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Metal Matrix Composite Analyzer (METCAN) User's Manual — Version 4.0

H.-J. Lee, P.K. Gotsis, P.L.N. Murthy, and D.A. Hopkins
Lewis Research Center
Cleveland, Ohio

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METAL MATRIX COMPOSITE ANALYZER

METCAN

USER'S MANUAL

VERSION 4.0

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Prepared by:

H.-J. Lee, P.K. Gotsis, P.L.N. Murthy, and D.A. Hopkins

NASA Lewis Research Center

Cleveland, Ohio 44135

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Section 1.0 Table of Contents

1.0 Introduction

METCAN (Metal Matrix Composite Analyzer) is a computer program developed at NASA Lewis Research Center (References 1-3) to simulate the high temperature nonlinear behavior of continuous fiber reinforced metal matrix composites. METCAN incorporates constituent material models along with composite micromechanical and macromechanical models to allow a comprehensive point analysis of the composite thermal and mechanical behavior.

The following sections provide a step by step outline of the procedure necessary to run METCAN. Section 1.0 will begin with an overview of METCAN, followed by a sample METCAN problem, the various geometric conventions employed, the structure of the input/output files, a description of the micromechanical unit cell model and the nonlinear constitutive relationship used in METCAN, and a list of notation. Section 2.0 will demonstrate the preparation of the primary input file, Section 3.0 will show how to create the constituent databank, and Section 4.0 will explain the contents of the postprocessing files.

The preparation of the following METCAN companion manuals is also planned for the near future:

i)   METCAN Demonstration Manual: This manual will contain various sample problems and details of the corresponding input and output files.

ii) METCAN Theoretical Manual: This manual will detail the theories used in the development of METCAN.

iii) METCAN Programmer's Manual: This manual will provide general programming information as well as describing the contents of the various subroutines that compose METCAN.

The potential user of METCAN is reminded that the program and the theoretical methodologies implemented in the code are in an evolutionary state. The present release of Version 4.0 is on a preliminary basis for evaluation purposes. Additional information regarding METCAN and the efforts to validate and verify the code can be found in References 4-8.

1.1 METCAN Overview

High temperature metal matrix composites offer great potential for use in advanced aerospace structural applications. The realization of this goal however, requires concurrent developments in (1) a technology base for fabricating high temperature metal matrix composite structural components, (2) experimental techniques for measuring thermal and mechanical characteristics, and (3) computational methods to predict their behavior. In the development of high temperature metal matrix composites, it proves beneficial to initially simulate their behavior through computational methods. Apart from providing an initial assessment of the metal matrix composite, this method helps to minimize the costly and time consuming experimental effort that would otherwise be required.

Recent research into computational methods for simulating the nonlinear behavior of high temperature metal matrix composites at NASA Lewis Research Center has led to the development of the METCAN (Metal Matrix Composite Analyzer) computer code. METCAN treats material nonlinearity at the constituent (fiber, matrix, and interphase) level, where the behavior of each constituent is modelled using a time-temperature-stress dependence. The composite properties are synthesized from the constituent instantaneous properties by making use of composite micromechanics and composite macromechanics models. Factors which affect the behavior of the composite properties include the fabrication process variables, the in-situ fiber and matrix properties, the bonding between the fiber and matrix, and/or the properties of the interphase between the fiber and matrix. The METCAN simulation is performed as a point-wise analysis and produces composite properties which can be incorporated into a finite element code to perform a global structural analysis. After the global structural analysis is

performed, METCAN decomposes the composite properties back into the localized response at the various levels of the simulation. At this point the constituent properties are updated and the next iteration in the analysis is initiated. This cyclic procedure is referred to as the integrated approach to metal matrix composite analysis and is depicted in Figure 1.1-1.
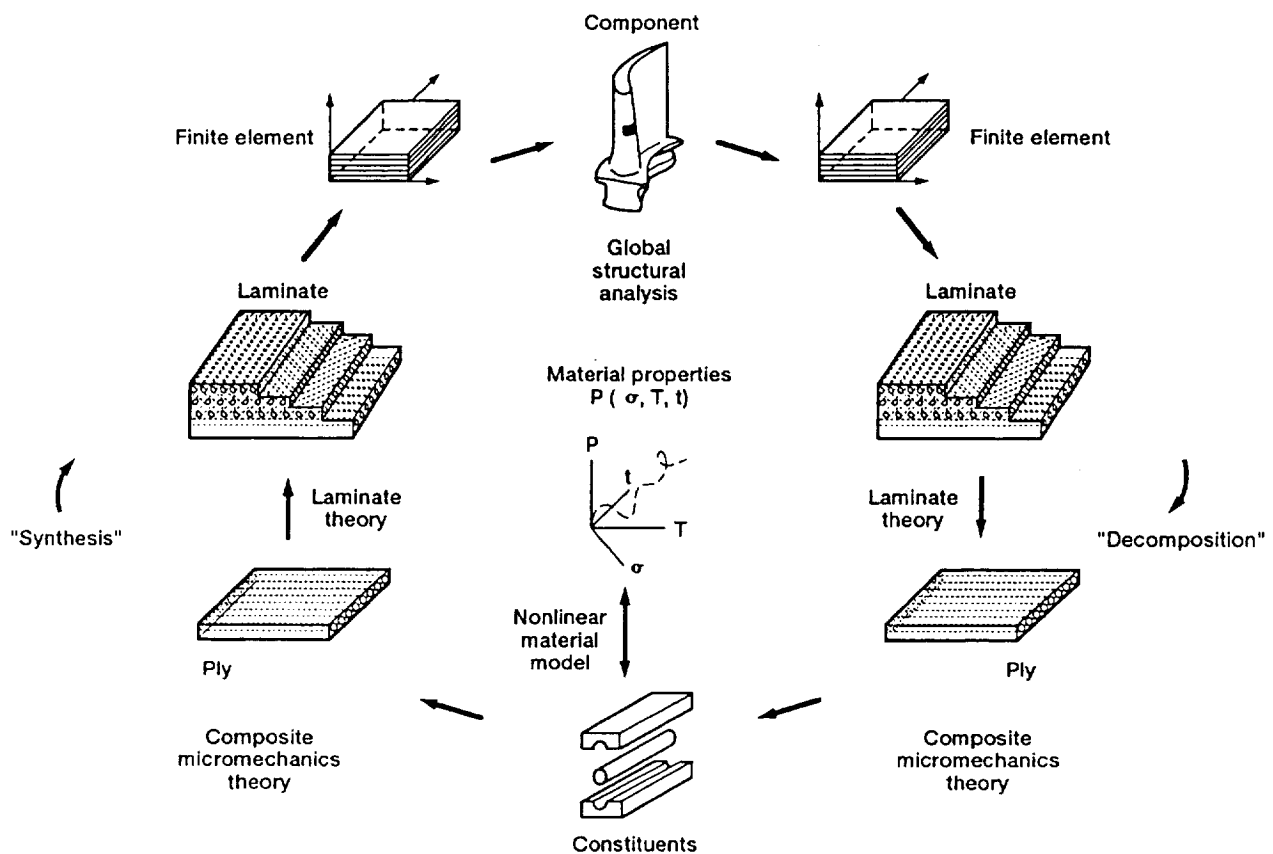
Figure 1.1-1—Integrated approach to metal-matrix composite analysis.

Figure 1.1-2 shows the modular structure of METCAN. In the development of METCAN, emphasis has been placed on maintaining a modular software structure and in providing a user friendly interface. The code features (1) a dynamic storage allocation scheme for efficient use of computer resources, (2) a resident databank of constituent material properties, (3) user selected control of the printed output, (4) generation of postprocessing files from which selected output can be extracted and represented graphically, (5) an input file structure which provides a straightforward user interface, and (6) separate modules containing the failure criteria, the material model, the composite micromechanics analysis, and the laminate analysis which are incorporated into METCAN.
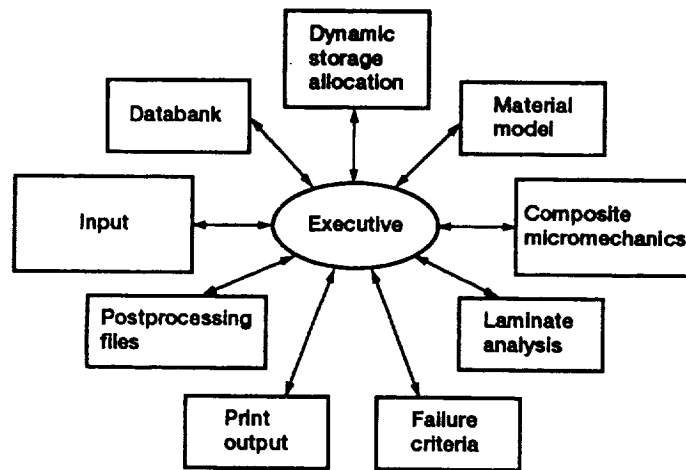
Figure 1.1-2—Modular structure METCAN.

1.2 An Initial METCAN Sample Case

A sample case with a step by step description of the procedure required to
prepare a METCAN input data file is provided below. This sample case is
presented at this point to give the user an overview of a typical application of
METCAN to model a problem before delving into specific details, as well as to
provide a starting point from which the user can easily utilize METCAN. The
problem to be modelled involves a two ply unidirectional metal matrix composite
composed of SiC fibers and a Ti-15-3 matrix. The fiber volume ratio is 30% ,no
voids are present, each ply has a thickness of 0.005 inches, and a perfect bond
(i.e. no interface) is assumed between the fiber and matrix. The composite is
processed from a temperature of 1200 F to room temperature and then subjected to
a monotonic load in the longitudinal direction at room temperature, as shown in
Figure 1.2-1. Results taken from the output containing the composite moduli at
the end of processing and at the end of loading are also included to demonstrate
one of the typical capabilities of METCAN.
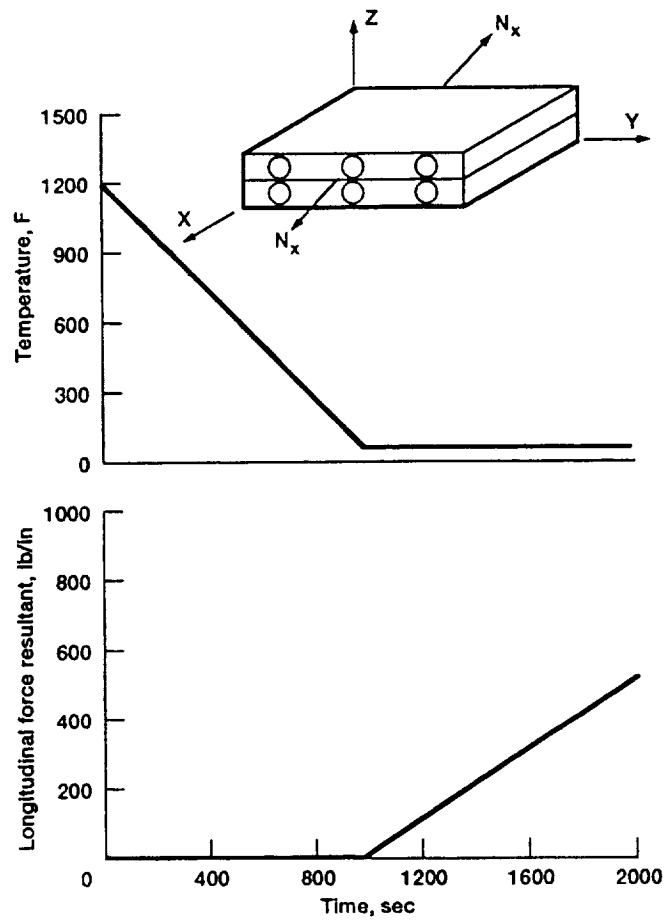
Figure 1.2-1—Sample case loading history.

The individual steps along with the corresponding line numbers in the input data file required to model this problem are presented in Table 1.2-1, while the input data file formed from these steps is shown in Figure 1.2-2. The line numbers shown in the table and figure are included for ease of reference between the two and are not part of the input data file. Typically, any problem can be modelled in ten steps, where each step requires one or more lines of data.

<u>Line</u> <u>No</u>.	-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

Line No.										
1	SAMPLE CASE FOR A TWO PLY SiC/Ti-15-3 METAL MATRIX COMPOSITE									
2	POST	F								
3	LDDIST	F								
4	PLY	1	1	0.0	0.005					
5	PLY	2	1	0.0	0.005					
6	MATCRD	1	.30	0. SICATI15						
7	CYCLES	1.0	1.0							
8	PRINT	ALL								
9	PRINTOPT	ALL								
10	INTRFACE	0								
11	TMLOAD	-2								
12	0.0	1000.	35							
13	1200.	1200.								
14	70.	70.								
15	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
16	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
17	1000.	2000.	25							
18	70.	70.								
19	70.	70.								
20	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.
21	500.	0.	0.	0.	0.	0.	0.	0.	0.	0.

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

Figure 1.2-2—Sample case input data file.

Table 1.2-1: Procedure in Preparing an Input Data File

Step No.	Line No.	Description of Data
1	1	Choose a problem title.
2	2	On the 'POST' record, select 'F' to indicate that the postprocessing files (used for graphical representation of the output) are not to be generated.
3	3	On the 'LDDIST' record, specify 'F' to show that the load redistribution algorithm (a post failure model used to simulate the progression of damage in the composite) is not to be used.
4	4	Use the 'PLY' record for the first ply. Specify the ply number as 1, the 'MATCRD' record identification number as 1, the ply orientation angle as $0°$, and the ply thickness as 0.005 inches.
	5	Use the 'PLY' record again for the second ply. Choose the ply number as 2, the 'MATCRD' identification number as 1 (indicating that both plies make use of the same 'MATCRD' record), the ply orientation angle as $0°$, and the ply thickness as 0.005 inches.
5	6	Specify on the 'MATCRD' record the material identification number from the 'PLY' records at 1, the fiber volume ratio as 0.30, the void volume ratio as 0.0, and the fiber and matrix code names used to retrieve the constituent material properties from the databank as SICA for the SiC fiber and TI15 for the Ti-15-3 matrix.

6	7	Use the 'CYCLES' record to select the number of thermal and mechanical cycles as 1.0, indicating that no degradation in material properties due to cyclic loading is desired.
7	8	Use the 'PRINT' record and specify 'ALL' to print all the possible output requests.
8	9	On the 'PRINTOPT' record, choose 'ALL' to indicate that the output requests from the previous card are to be printed after each step in the analysis.
9	10	Use the 'INTRFACE' record with a '0' to specify that an interface is not modelled.
10	11	Use the 'TMLOAD' record to designate the loading history. Selecting a '-2' indicates that a linear loading history split into two segments is to be used. The first segment simulates the processing of the composite, while the second segment models the application of the mechanical load.
	12	Set the time range for the first segment from 0 to 1000 seconds and assign this segment 35 increments.
	13	Specify the temperature of plies 1 and 2 at the start of the first segment (0 seconds) as 1200 F.
	14	Specify the temperature of plies 1 and 2 at the end of the first segment (1000 seconds) as 70 F.
	15	Indicate that there are no mechanical loads at the start of the first segment by choosing '0.0' for all entries.
	16	Indicate that there are no mechanical loads at the end of the first segment by choosing '0.0' for all entries.
	17	Set the time range for the second segment from 1000 to 2000 seconds and assign this segment 25 increments.

18	Specify the temperature of plies 1 and 2 at the start of the second segment (1000 seconds) as 70 F.
19	Specify the temperature of plies 1 and 2 at the end of the second segment (2000 seconds) as 70 F.
20	Indicate that there are no mechanical loads at the start of the second segment by choosing '0.0' for all entries.
21	Indicate that at the end of second segment there is a longitudinal force resultant of 500 lb/in applied. This means that the load increases monotonically from 0 at 1000 seconds to 500 lb/in at 2000 seconds.

Once all ten steps have been completed and the input data file generated, the METCAN program can be executed. Results of the METCAN simulation will in turn be written to an output file. Typical results from the output file for the composite moduli at two points in the loading history are shown in Table 1.2-2. A more detailed version of this input data file along with two other input data files can be found in Section 2.13.

Table 1.2-2 Typical Results for Composite Moduli Taken from METCAN Output

Moduli (Msi)	End of Processing	End of Loading
E_{C11}	26.63	24.97
E_{C22}	16.66	16.52
E_{C33}	16.66	16.52
E_{C12}	6.61	6.55
E_{C23}	6.26	6.23
E_{C31}	6.61	6.55

1.3 METCAN Geometric Conventions

The global and local coordinate systems employed in METCAN and the conventions for ply ordering, measuring orientation angle, and loading are presented in the following sections.

1.3.1   Global (Laminate) Coordinate System

Figure 1.3.1-1 shows the global or laminate coordinate system for an arbitrary laminate. The convention is that the x-axis is orientated parallel to the direction of the fiber for a $0°$ ply, the y-axis is orientated perpendicular to this fiber direction, and the z-axis is orientated through the thickness dimension of the composite. The x-axis direction is also referred to as the longitudinal direction, while the y-axis and z-axis directions are called the in-plane transverse and out-of-plane transverse directions, respectively.
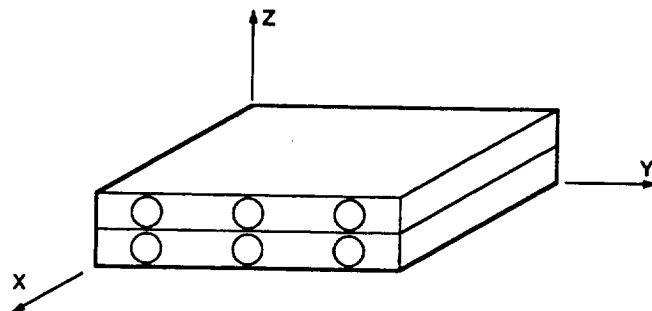
Figure 1.3.1-1—METCAN global (laminate) coordinate system.

1.3.2   Local (Material) Coordinate System

The local or material coordinate system is depicted in Figure 1.3.2-1. The 1-axis is orientated parallel to the direction of the fiber, the 2-axis is orientated perpendicular to this fiber direction, and the 3-axis is orientated through the thickness dimension of the ply.
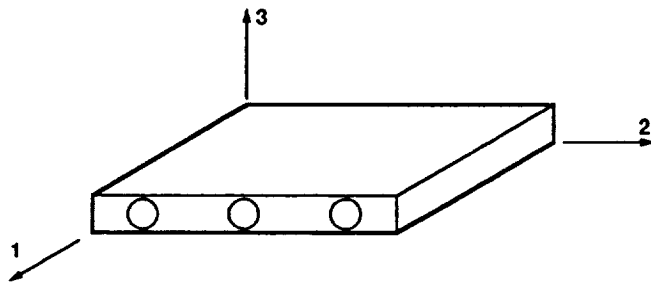
Figure 1.3.2-1—METCAN local (material) coordinate system.

1.3.3   Ply Ordering Convention

The ply ordering convention employed in METCAN is shown in Figure 1.3.3-1.   The first ply is placed at the plane z=0.   Subsequent plies are stacked on top of the first ply in the positive z direction.
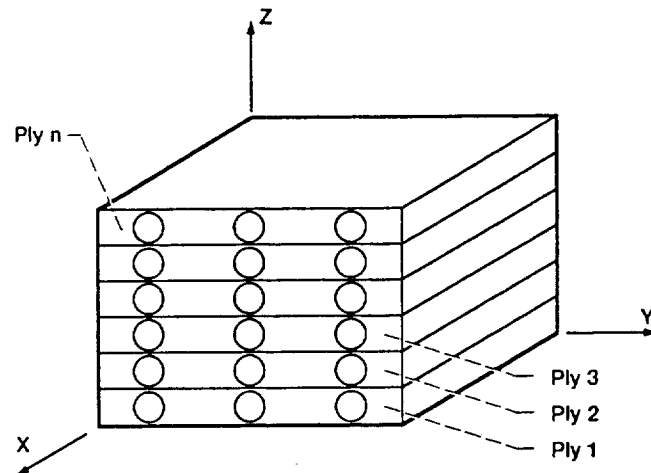
Figure 1.3.3-1—METCAN ply ordering convention.

1.3.4 Orientation Angle Convention

The orientation angle of a ply is taken as the angle between the local coordinate system and the global coordinate system, as shown in Figure 1.3.4-1. The positive convention for angle θ is measured counter-clockwise.
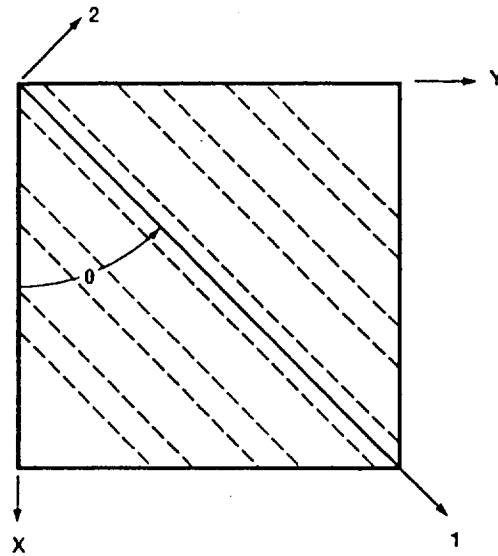
X, Y : global coordinate axes
1, 2 : local coordinate axes
θ : angle between global and local axes

Figure 1.3.4-1—METCAN ply orientation angle convention.

1.3.5   Loading Conventions

The positive sign conventions for the various loadings in METCAN are presented in Figure 1.3.5-1. It should be noted that the METCAN input file assumes stresses and moments to be integrated resultant quantities in the usual sense from plate and shell theory. Dimensions for the force resultants are force per unit width, while moment resultants are moment per unit width. The in-plane force resultants are represented by N_x, N_y, and N_{xy}, while out-of-plane force resultants are represented by Q_{xz} and Q_{yz}. Moment resultants are symbolized by M_x, M_y, and M_{xy} and the upper and lower surface pressures are denoted by P_u and P_l, respectively.
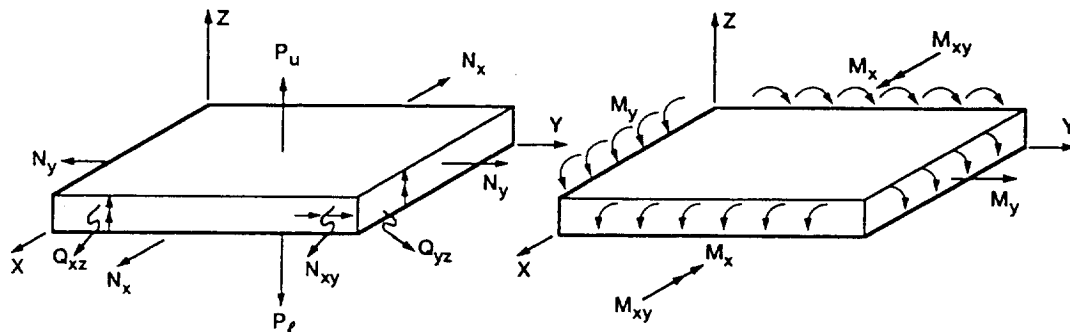
Figure 1.3.5-1—METCAN positive loading conventions.

1.4 METCAN Input/Output File Structure

The input/output file structure in METCAN is comprised of four different files as shown in Figure 1.4-1. Three out of the four files (the two input files and the primary output file) will be utilized for all analyses. The fourth file is actually a set of ten postprocessing files which can be optionally generated as defined by the user. The primary input file contains information regarding the ply material system, the loading history, and identifies the constituent properties to be retrieved from the second input file. The second input file is called the constituent databank and contains the room temperature constituent properties for various materials. Data from the two input files is used to initiate the METCAN analysis. Results from the analysis are in turn generated as the primary output file. The primary output file can be tailored by the user (as defined in the primary input file) to produce various combinations of the available output requests. The available output requests include constituent mechanical and thermal properties, micromechanical stresses and strains in the three subregions of the unit cell for each ply, ply mechanical and thermal properties, and composite properties. Another group of ten output files, the postprocessing files, can also be optionally generated (again defined through the primary input file). The postprocessing files contain the same information found in the primary output file, but in a format more amenable to manipulation for graphical representation. The following sections give a brief description of each input and output file.
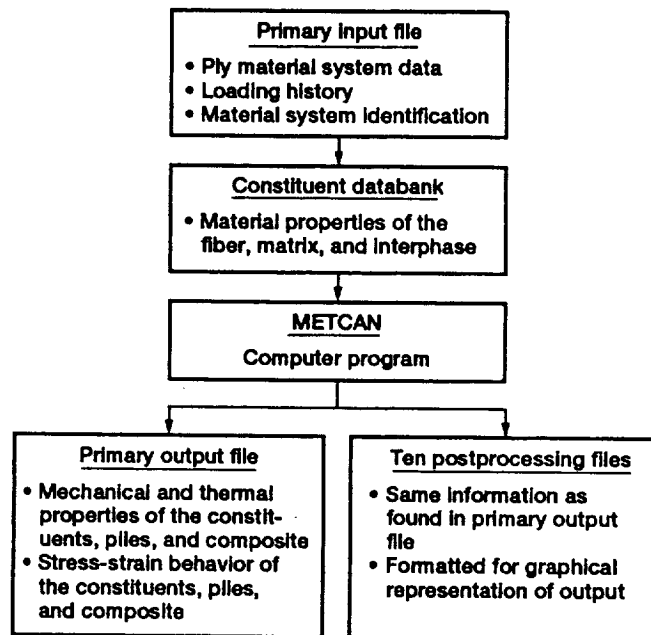
Figure 1.4-1—METCNAN input/output file structure.

1.4.1   Primary Input File

The primary input file contains data used to initiate the METCAN analysis. The file performs the following four functions:

1) Specify the composite geometry. Variables such as ply thickness, orientation angle, fiber volume ratio, and interphase thickness are prescribed.

2) Specify the loading history. The fabrication conditions, thermal and mechanical loadings, and thermal and mechanical cyclic loadings can be detailed.

3) Identify the constituent materials. The code names of the fiber, matrix, and interphase to be retrieved from the constituent databank are specified.

4) Select output information generation. Allows the user to tailor the primary output file to the user's requirements and to control the generation of the ten postprocessing files.

These functions of the primary input file are depicted in Figure and 1.4.1-1 and the specific data records necessary to prepare the primary input file will be addressed in Section 2.0.
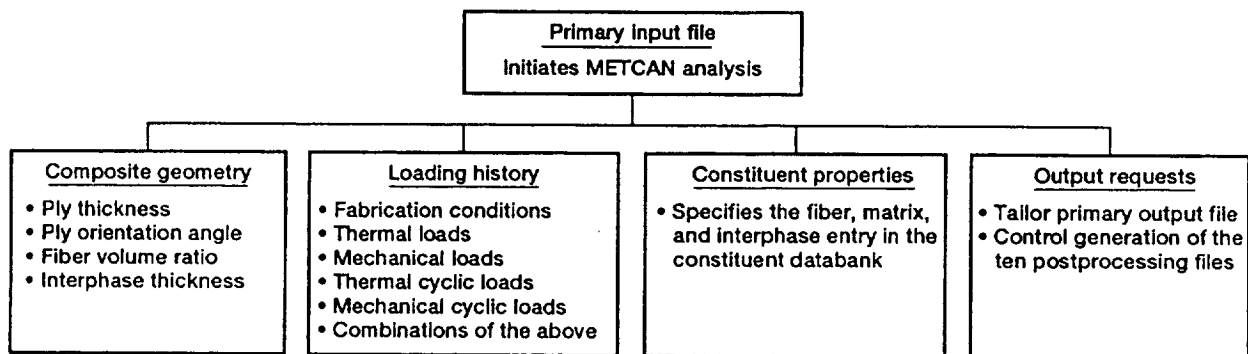
Figure 1.4.1-1—Functions of the primary input file.

1.4.2   Constituent Databank File

METCAN utilizes a constituent databank containing room temperature constituent (fiber, matrix, and interphase) properties of various materials. The primary purpose of the databank is to relieve the user of the repetitive burden of including this information as part of the primary input file. By assigning a unique code name for each constituent in the databank, the user merely has to specify the code name in the primary input file to acquire the numerous properties for a specific constituent. The assignment of unique code names also makes it convenient to update the databank as material properties become available. The databank is organized into three sections; the first for fiber properties, the second for matrix properties, and the third for interphase properties. Figure 1.4.2-1 shows the databank organization and the properties contained for each constituent. Details on preparing the constituent databank are found in Section 3.0.

Constituent databank

Contains room temperature material properties of the fiber, matrix and interphase

Fiber material properties	Matrix material properties	Interphase material properties
• Fiber diameter	• Weight density	• Weight density
• Weight density	• Modulus	• Interphase thickness
• Melting temperature	• Poisson's ratio	• Modulus
• Moduli	• Coefficient of thermal expansion	• Poisson's ratio
• Poisson's ratios	• Thermal conductivity	• Coefficient of thermal expansion
• Coefficients of thermal expansion	• Heat capacity	• Thermal conductivity
• Thermal conductivities	• Strengths	• Heat capacity
• Heat capacity	• Strains	• Strengths
• Strengths	• Void thermal conductivity	• Strains
• Reference stresses	• Melting temperature	• Void thermal conductivity
• Reference stress-rates	• Reference stresses	• Melting temperature
• Exponents for multi-factor interaction relationship	• Reference stress-rates	• Reference stresses
	• Exponents for multifactor interaction relationship	• Reference stress-rates
		• Exponents for multifactor interaction relationship

Figure 1.4.2-1—Organization of the constituent databank.

1.4.3   Primary Output File

Results of the METCAN simulation are generated to a primary output file.
The user has the flexibility to tailor the primary output file by specifying
various combinations of the available output requests as part of the primary
input file (see the PRINT input data record in Section 2.0). The simulation
results comprise information at three levels, the laminate, ply, and
constituent levels. The three levels of the analysis and the various
information associated with each level are defined in Figure 1.4.3-1.

```
                    ┌─────────────────────────────────────────┐
                    │          Primary output file            │
                    │   Output reporting tailored by the user  │
                    └─────────────────────────────────────────┘
```

Composite	Ply	Constituents (fiber, matrix, and interphase)
• 2-D and 3-D material properties • 3-D stress-strain relation • Force-displacement relations • Reduced membrane and bending stiffnesses • Stress concentration factors around a circular hole in an infinite plate • Elastic and material properties for a finite element analysis	• Load/time step history • Failure index for each ply • Ply properties • Ply stress-strain relations in local coordinates	• Echo reference constituent material properties found in the databank • Instantaneous values of constituent properties • Microstresses and micro-strains for each constituent in local coordinates

Figure 1.4.3-1—Levels of analysis information available in the primary output file.

1.4.4   Postprocessing Output Files

The ten postprocessing output files are optionally generated at the user's request (see the POST input data record in Section 2.0). These ten files essentially contain the same information generated in the primary output file, but in a format from which selected output quantities can be extracted by the user and imported into graphics packages for convenient representation. The ten postprocessing output files and their contents are described in Figure 1.4.4-1. A more detailed description regarding the ten postprocessing files can be found in Section 4.0.

Ten postprocessing files

Contains the same information presented in the primary output file, but formatted for graphical representation

| Constituent level | Ply level | Composite level |

File 2
Time and instantaneous fiber properties

File 1
Time and temperature for each ply

File 10
Time and instantaneous composite properties

File 3
Time and instantaneous matrix properties

File 5
Time and instantaneous ply properties

File 4
Time and instantaneous interphase properties

File 9
Time, ply stresses, ply strains, composite stresses, and composite strains

File 6
Time, fiber microstresses, and fiber microstrains

File 7
Time, matrix microstresses, and matrix microstrains

File 8
Time, interphase microstresses, and interphase microstrains

Figure 1.4.4-1—Contents of the ten postprocessing files.

1.4.5   Input/Output User's Information

The METCAN source code consists of approximately 7400 lines of FORTRAN statements. The program has been compiled using a variety of FORTRAN 77 compilers on hardware ranging from microcomputers to supercomputers with relative ease. It is not anticipated that the user will have any difficulty with program installation.

The file system for METCAN consists of:

I)	The primary input file	FORTRAN I/O Unit 5
II)	The constituent databank input file	FORTRAN I/O Unit 8
III)	The primary output file	FORTRAN I/O Unit 6
IV)	The ten postprocessing output files:	
	1) Postprocessing File 1	FORTRAN I/O Unit 31
	2) Postprocessing File 2	FORTRAN I/O Unit 32
	3) Postprocessing File 3	FORTRAN I/O Unit 33
	4) Postprocessing File 4	FORTRAN I/O Unit 34
	5) Postprocessing File 5	FORTRAN I/O Unit 35
	6) Postprocessing File 6	FORTRAN I/O Unit 36
	7) Postprocessing File 7	FORTRAN I/O Unit 37
	8) Postprocessing File 8	FORTRAN I/O Unit 38
	9) Postprocessing File 9	FORTRAN I/O Unit 39
	10) Postprocessing File 10	FORTRAN I/O Unit 40

1.5 METCAN Flowchart

The METCAN flowchart provides details of the execution sequence for a typical analysis and is shown in Figure 1.5-1. The analysis is initiated through the two input files. The primary input file contains the ply data, loading history, output requests, and specifies the constituent properties to be retrieved from the second input file, the constituent databank. Once the data from these two input files are read into METCAN, the code determines the ply thermal and mechanical properties followed by a laminate analysis to find the composite properties for the first increment. From this point, METCAN proceeds to the incremental iterative portion of the analysis. The microstresses in the various sub-regions of the unit cell are then calculated. These results are used in turn to update the constituent mechanical properties, the constituent thermal properties, and the constituent strength limits. The updated constituent properties are used in conjunction with micromechanics theory to determine the ply thermal and mechanical properties. Subsequently, a laminate analysis is performed to find the composite properties. At this point convergence is checked. If the convergence criteria is not met, the previously detailed steps are repeated until convergence is satisfied.

Once convergence is achieved, results from the analysis are generated to the two output files according to the user specified requests. The first output file actually consists of a group of ten files referred to as the postprocessing files. These files are optionally generated by the user and basically contain the same information found in the other output file, the primary output file. The primary output file can be tailored by the user to contain various combinations of the results generated in the analysis. After the output requests have been generated, the incremental iterative

analysis is performed for the next load increment and these results

generated to the output files. This cycle is continued until all the load

increments have been analyzed.
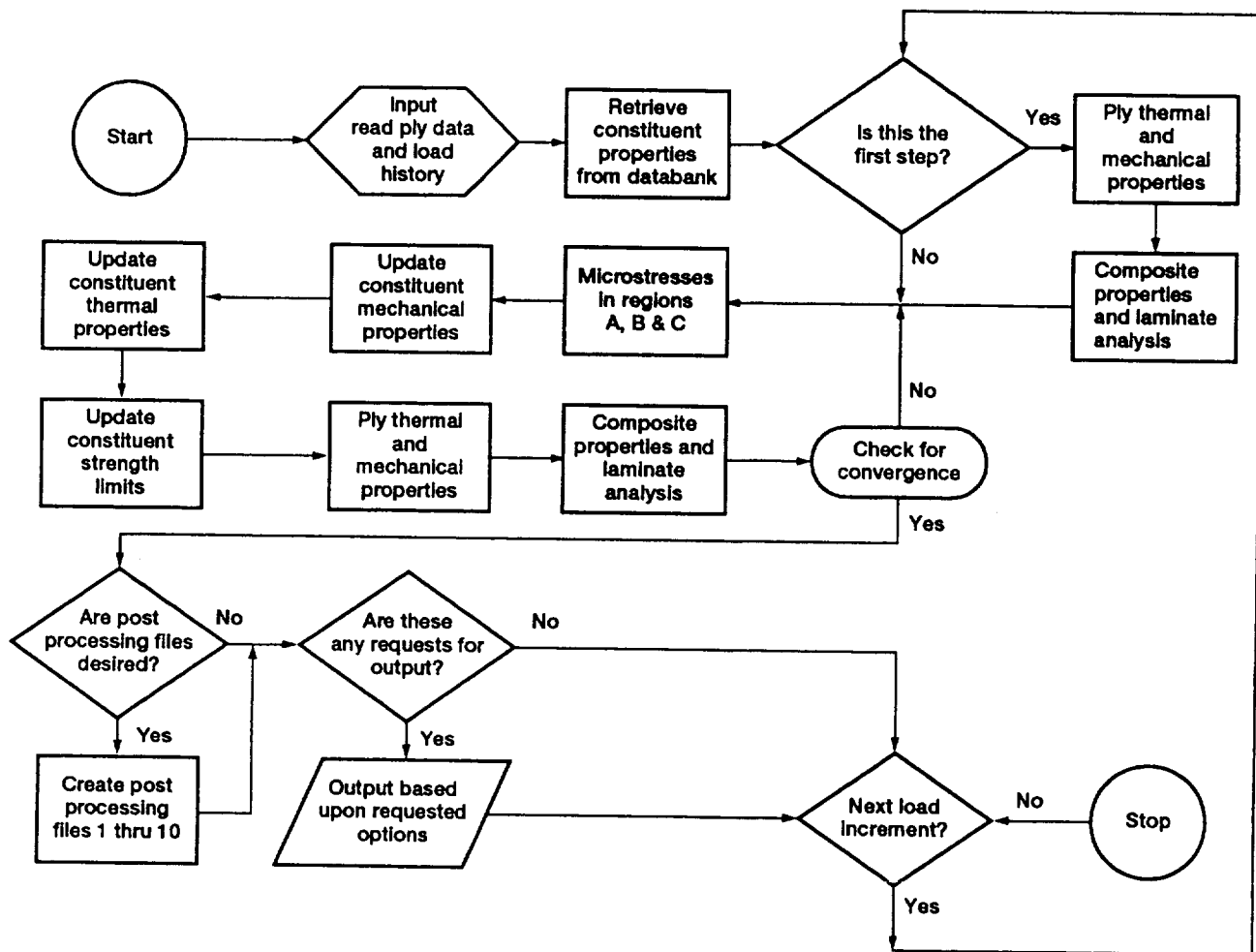
Figure 1.5-1—METCAN flowchart.

Two features of the theoretical basis of METCAN are (1) the multifactor interaction relationship to functionally represent the nonlinear behavior of metal matrix composites at the constituent level and (2) the generic unit cell to derive the micromechanics equations. These two aspects are described in the following sections.

1.6.1   Nonlinear Constitutive Material Model

METCAN treats material nonlinearity at the constituent level through the
incorporation of a multifactor interaction relationship (MFIR). The MFIR
models the material behavior in the form of a time-temperature-stress dependence
of the constituent properties. The MFIR and the rationale for its utilization
are expressed in Figure 1.6.1-1. The form of the MFIR is a product function of
terms raised to specified powers that define the values of the material property
(P) of the fiber, matrix, and interphase. The constituent properties (P) which
are determined through the MFIR are modulus, Poisson's ratio, strength,
coefficient of thermal expansion, and heat capacity. For each fiber, matrix,
and interphase property, there is generally a distinct set of values of the
exponents necessary to express the functional definition of the property. The
various exponents are determined from the appropriate experimental data. If
there is a lack of experimental data, default values are used as an
approximation. The values for the exponents are defined in the constituent
databank for the various fibers, matrices, and interphases. The default values
of the exponents are listed under the EXPONENTS record of each constituent in
Section 3.0.

$$\frac{P}{P_O} = \left[\frac{T_F - T}{T_F - T_O}\right]^n \left[\frac{S_F - \sigma}{S_F - \sigma_O}\right]^m \left[\frac{\dot{S}_F - \dot{\sigma}_O}{\dot{S}_F - \dot{\sigma}_O}\right]^\ell \left[\frac{\dot{T}_F - \dot{T}}{\dot{T}_F - \dot{T}_O}\right]^k \left[\frac{R_F - R}{R_F - R_O}\right]^p \dots$$

$$\dots \left[\frac{N_{MF} - N_M}{N_{MF} - N_{MO}}\right]^q \left[\frac{N_{TF} - N_R}{N_{TF} - N_{TO}}\right]^r \left[\frac{t_F - t}{t_F - t_O}\right]^s \dots$$

Subregions of intralaminar nonuniformity
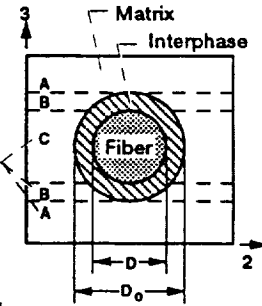
Rationale:

- Gradual effects during most range, rapidly degrading near final stages
- Representative of the in situ behavior for fiber, matrix, interphase, coating
- Introduction of primitive variables (PV)
- Consistent in situ representation of all constituent properties in terms of PV
- Room–temperature values for reference properties
- Continuous interphase growth
- Simultaneous interaction of all primitive variables
- Adaptability to new materials
- Amenable to verification inclusive of all properties
- Readily adaptable to incremental computational simulation

Notations:

P – property; T – temperature; S – strength; R – metallurgical reaction; N – number of cycles; D – diameter; σ – stress; t – time; over dot – rate; subscripts: O – reference; F – final; M – mechanical; T – thermal

Figure 1.6.1-1—Assumed multifactor interaction relationship to represent the various factors which influence in Situ constituent materials behavior.

1.6.2   Micromechanical Unit Cell and Subregions

There are two alternative versions of the generic unit cell model used in METCAN, as shown in Figure 1.6.2-1. A typical unit cell consists of a fiber and a matrix with or without an interphase. The unit cell is further subdivided into two or three subregions depending on the presence of an interphase. If an interphase is present, subregion A consists entirely of matrix material, subregion B consists of matrix and interphase, and subregion C consists of fiber, matrix, and interphase. If there is no interphase, two subregions exist. Subregion A consists entirely of matrix material, while subregion C consists of fiber and matrix, and subregion B does not exist.

A: Matrix
B: Matrix and interphase
C: Matrix, fiber, and interphase

Regions of
constituent
material
nonuniformity
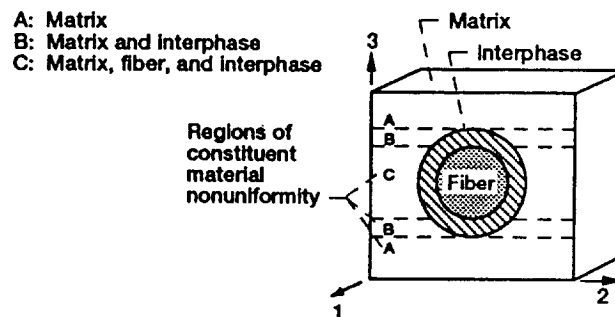
(a) Unit cell with an interphase.

A: Matrix
C: Matrix and fiber

Regions of
constituent
material
nonuniformity
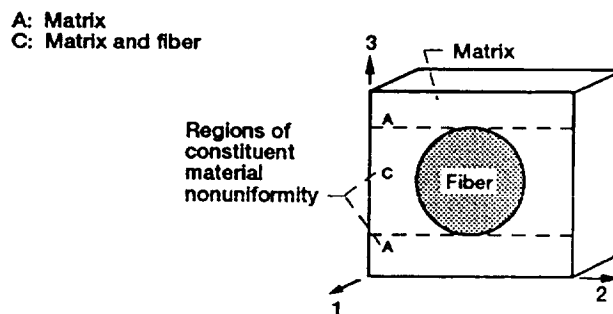
(b) Unit cell without an interphase.

Figure 1.6.2-1—METCAN generic unit cells.

1.7   Notation and Units

The notation used in the subsequent sections along with the corresponding units of measure are explained below. In principle, any consistent system of units may be used. However, the user should note that the sample input files and the sample constituent databank provided with METCAN are based on the given units.

Symbols

k	Volume fraction	--
t	Time	sec
t_1	Thickness	in
z	Distance from reference plane	in
C	Stress-strain relationship tensor	psi
C_p	Heat capacity	Btu/lb
D_f	Fiber diameter	in
E	Normal modulus	psi
G	Shear modulus	psi
K	Thermal conductivity	Btu/hr/in/$^\circ$F
M	In-plane moment resultant	lb-in/in
N	In-plane stress resultant	lb/in
N_f	Number of fibers per bundle	--
N_M	Number of mechanical load cycles	--
N_T	Number of thermal load cycles	--
P_1	Lower surface pressure	psi
P_u	Upper surface pressure	psi
Q	Out-of-plane shear resultant	lb/in
S	Strength	psi
T	Temperature	$^\circ$F

T_M	Melting temperature	°F
α	Coefficient of thermal expansion	in/in/°F
ψ_{MDE}	Modified distortion energy	--
ε	Strain	%
ν	Poisson's ratio	--
ρ	Density	lb/in^3
σ	Stress	psi
$\dot{\sigma}_H$	Limit-state value of stress rate	psi/sec
θ	Orientation angle	degrees

Superscripts

| $\cdot$ | Derivative with respect to time |

Subscripts

c	Composite (laminate) related quantity
d	Interphase related quantity
f	Fiber related quantity
i	Index for i-th load/time step
l	Lamina (ply) related quantity
m	Matrix related quantity
v	Void related quantity
x,y,z	Global coordinate system axes
A,B,C	Unit cell sub-regions
T,C,S,τ	Tension, compression, shear, and torsion, respectively
1,2,3	Local coordinate system axes

Section 2.0 Table of Contents

2.0 Input Data Records

The METCAN input file structure provides a straightforward user interface. The input file is organized into different records in a specific order. Thus each record must be included in the input file in the order they are defined in the following sections. Each record can be composed of one or several physical lines of data. Each line of data has a fixed format of ten eight-column fields (except for the title and comment records). The usual convention is that each record is identified by a character mnemonic in the first field of the data. The character mnemonics and other alphanumeric data are entered with character format (A8), while integer data are entered in integer format (I8). Real data can be entered in either floating point (F8) or exponential (E8) formats. Character, integer, and exponential formats must be right justified, while the floating point format can be entered anywhere in the appropriate field. Figure 2.0-1 describes the individual records required in the input file, the mnemonic which identifies the record, the number of lines of data which comprise each record, and the order in which each record is read by METCAN. A description and example of each record is given in the following sections. Samples of complete input files are provided at the end of this section for illustration.
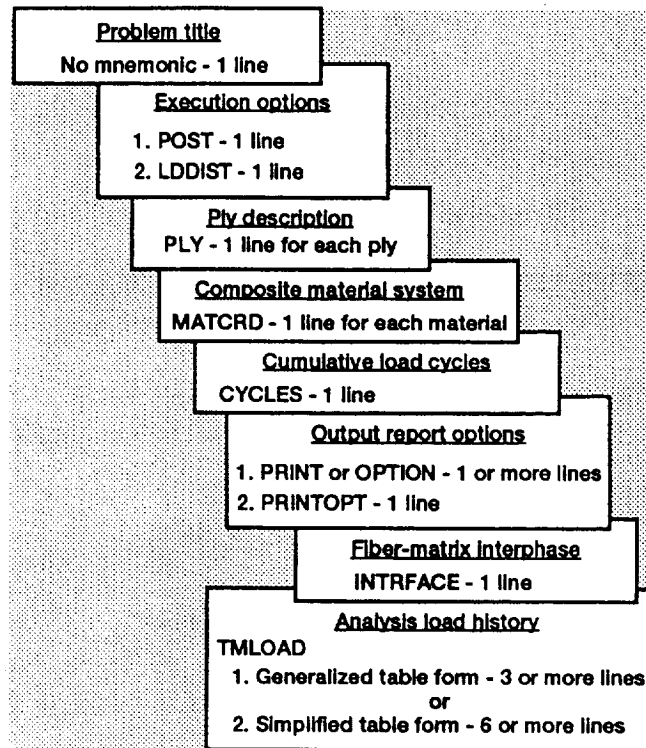
Figure 2.0-1—Composition of the primary input data file.

The boxes in the figure contain the following:

Problem title
No mnemonic - 1 line

Execution options
1. POST - 1 line
2. LDDIST - 1 line

Ply description
PLY - 1 line for each ply

Composite material system
MATCRD - 1 line for each material

Cumulative load cycles
CYCLES - 1 line

Output report options
1. PRINT or OPTION - 1 or more lines
2. PRINTOPT - 1 line

Fiber-matrix interphase
INTRFACE - 1 line

Analysis load history
TMLOAD
1. Generalized table form - 3 or more lines
or
2. Simplified table form - 6 or more lines

2.1 Input Data Record: $

Description: Comments

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
$ COMMENT
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
$ Any comment, up to 79 characters long.
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	$	A1	1	Mnemonic name
2	COMMENT	A79	2-80	Comment

Remarks:

1.   Comments can be inserted anywhere in the input data file.

.

2.2 Input Data Record: (No Mnemonic)

Description: Problem title

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
TITLE
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
Any problem title, up to 80 characters long.
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	TITLE	A80	1-80	Problem title

Remarks:

1.   This record has no mnemonic.

2.   The first non-comment line of the input file is read as the title record.

2.3 Input Data Record: POST

Description: Postprocessing files generation option

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   POST      ID
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   POST       T
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	POST	A8	1- 8	Mnemonic name
2	ID	A8	9-16	File generation option

Remarks:

1. There are two choices for the ID:

    T will result in the generation of ten postprocessing files

    F will not generate the postprocessing files

2.4 Input Data Record: LDDIST

Description: Load redistribution option

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

  LDDIST      ID

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

  LDDIST       F

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	LDDIST	A8	1- 8	Mnemonic name
2	ID	A8	9-16	Load redistribution option

Remarks:

1. The load redistribution algorithm employs post failure models to simulate the progression of damage in the composite. Accumulated stresses are redistributed among the constituents at each load step.

2. This option is useful when simulating composites containing highly nonlinear matrix materials.

3. There are two choices for the ID:

    T will invoke the redistribution option

    F will not invoke the redistribution option.

2.5 Input Data Record: PLY

Description: Defines each ply of the composite

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   PLY     PID     MID    θ₁      t₁
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   PLY       1       1   45.     0.005
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	PLY	A8	1- 8	Mnemonic name
2	PID	I8	9-16	Ply identification number
3	MID	I8	17-24	Material system identification number
4	θ_1	F8	25-32	Orientation angle of the ply
5	t_1	F8	33-40	Ply thickness

Remarks:

1.   Each ply of the composite is defined by a separate PLY record.

2.   The ply ordering sequence is shown in Section 1.3.3.

3.   Each different MID must have a corresponding MID on a MATCRD record.

4.   The orientation angle is taken as the angle of the ply material coordinate system with respect to the structural coordinate system, shown in Section 1.3.4.

5.   If the t_1 field is left blank, the thickness is defaulted to 0.005 inches.

2.6 Input Data Record: MATCRD

Description: Defines a composite material system (i.e. fiber/matrix composition)

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   MATCRD     MID    k_f     k_v     CODE
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
   MATCRD       1   0.35    0.0    SICATI15
-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	MATCRD	A8	1- 8	Mnemonic name
2	MID	I8	9-16	Material system identification number
3	k_f	F8	17-24	Fiber volume fraction
4	k_v	F8	25-32	Void volume fraction
5	CODE	A8	33-40	Fiber and matrix code names

Remarks:

1. A separate MATCRD record must be defined for each different material system in the composite.

2. Each different MID field must have a corresponding MID on a PLY record.

3. The fiber volume fraction is restricted to the range:

$$0.05 < k_f < 0.78$$

4. The CODE field specifies the four letter code names of the fiber and matrix and identifies the corresponding entries in the constituent databank.

2.7 Input Data Record: CYCLES

Description: Defines cumulative mechanical and thermal load cycles

Format and Example:

```
--------+--------+--------+--------+-------+-------+-------+-------+-------+-------+
CYCLES  N_M       N_T      N_MFf     N_TFf    N_MFm    N_TFm    N_MFi    N_TFi
--------+--------+--------+--------+-------+-------+-------+-------+-------+-------+
CYCLES  1000.    10.     1.0E+06  4.0E+02 1.0E+06 4.0E+02 1.0E+06 4.0E+02
--------+--------+--------+--------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	CYCLES	A8	1- 8	Mnemonic name
2	N_M	F8	9-16	Number of mechanical cycles
3	N_T	F8	17-24	Number of thermal cycles
4	N_{MFf}	F8	25-32	Fiber mechanical cycles limit
5	N_{TFf}	F8	33-40	Fiber thermal cycles limit
6	N_{MFm}	F8	41-48	Matrix mechanical cycles limit
7	N_{TFm}	F8	49-56	Matrix thermal cycles limit
8	N_{MFi}	F8	57-64	Interface mechanical cycles limit
9	N_{TFi}	F8	65-72	Interface thermal cycles limit

Remarks:

1. The CYCLES record specifies an option to degrade the material properties due to cumulative mechanical and thermal load cycles.

2. Specifying a value of 1.0 for N_M nullifies mechanical cyclic effects. Similarly, a value of 1.0 for N_T nullifies thermal cyclic effects. A value of 1.0 only nullifies the specified cycling.

3. The limit state values of the mechanical and thermal cycles (T_{MF} and T_{TF}) can be specified for each constituent on this record. These fields are optional.

4. The default limit state value of the mechanical cycle (N_{MF}) is set at 10^6 cycles.

5. The default limit state value of the thermal cycle (N_{TF}) is set internally at 400 cycles.

6. In the case where both cumulative mechanical and thermal cycles and a linear load history are desired additional fields are required on the TMLOAD (Simplified Table Form) record to differentiate between cyclic and static loads. See the TMLOAD (Simplified Table Form) record.

7. When cycling is specified, output information for the cycling portion of the load history is generated only for the last cycle.

2.8 Input Data Record: PRINT

Description: Defines output request options

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

   PRINT OUTCODE

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

   PRINT   MICRO

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Alternate Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

   OPTION   OUTNUM

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+

   OPTION      10

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	PRINT	A8	1- 8	Mnemonic name
2	OCODE	A8	9-16	Output option request code

Alternate Form:

Field No.	Field Name	Format	Columns	Description
1	OPTION	A8	1- 8	Mnemonic name
2	OUTNUM	I8	9-16	Output option request number

2-12

Remarks:

1. This record allows the user to tailor the output generation.

2. There are two alternative forms to specify the output requests:

    (i) An output code form (OUTCODE)

    (ii) An output number form (OUTNUM)

    The output code form is recommended, since the output number form will be

    phased out in subsequent versions.

3. The available output request options are:

Output Code OUTCODE	Output No. OUTNUM	Description
ALL	0	Complete report of all available information
CONSTI	8	Laminate constitutive relationships
DISPFOR	11	Displacement-force relationships
FEMDATA	10	Information for finite element analysis
FLINDEX	5	Report of failure index
LDSTEP	29	Information for current load/time step
MICRO	28	Constituent total stresses and strains for each ply
NONE	99	Output reporting suppressed
PLYRESP	12	Ply properties and response variables
PLYSTRS	15	Ply stresses and strains
PROPCOM	7	Laminate 2-D and 3-D properties
PROPCUR	27	Constituent instantaneous properties
PROPREF	26	Constituent reference properties
REDSTIF	9	Laminate reduced membrane and bending stiffnesses

STRCON	16	Stress concentration factors around a circular hole in an infinite plate
STRSINF	18	Stress-strain influence coefficients
STRSTRN	6	Laminate stress-strain relationships and MSC/NASTRAN MAT9 record

4. There is no limit to the number of output options which can be requested, however each output option requires a separate record.

5. The output reporting frequency is controlled through the PRINTOPT record.

2.9 Input Data Record: PRINTOPT

Description: Defines the output reporting frequency

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
PRINTOPT   PRID
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
PRINTOPT    10
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	PRINTOPT	A8	1- 8	Mnemonic name
2	PRID	A8 or I8	9-16	Output reporting frequency

Remarks:

1. This record is optional. The default is to print the output for each load step of the analysis.

2. There are three choices for the PRID:

    (i)   ALL   Output is produced for each load step of the analysis

    (ii)   LAST   Output is produced for only the last load step of the analysis

    (iii) i   Output is produced after every i-th step of the analysis

2.10 Input Data Record: INTRFACE

Description: Defines an interphase between the fiber and matrix

Format and Example:

```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
INTRFACE    INID   t
                    d
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
INTRFACE     1   0.10
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Field No.	Field Name	Format	Columns	Description
1	INTRFACE	A8	1- 8	Mnemonic name
2	INID	I8	9-16	Interphase indicator
3	t_d	F8	17-24	Interphase thickness

Remarks:

1.   There are two choices for the INID field:

   (i) 0   An interphase is not considered in the analysis

   (ii) 1   An interphase is considered in the analysis

2.   If an interphase is not considered (INID=0), then perfect bonding between the fiber and matrix is assumed.

3.   The field t_d is only valid for an INID choice of 1 and specifies the thickness of the interphase as a fraction of the fiber diameter. The thickness performs the same function as the fiber and matrix code names in the MATCRD record. It specifies the interphase entry in the constituent databank containing the room temperature material properties of the interphase.

4.   Only one interphase can be specified in the input data file.

2.11 Input Data Record: TMLOAD (Generalized Table Form)

Description: Defines analysis load history with discrete points

Format and Example:

TMLOAD	NLS

TMLOAD	4

t_i	$T_{l\ 1,i}$	$T_{l\ 2,i}$	....
0.0	2000.	1800.	....

$T_{l\ k,i}$	....	$T_{l\ n,i}$
1200.	....	1000.

$N_{x,i}$	$N_{y,i}$	$N_{xy,i}$	$M_{x,i}$	$M_{y,i}$	$M_{xy,i}$	$Q_{xz,i}$	$Q_{yz,i}$	$P_{l,i}$	$P_{u,i}$
100.	100.	0.	150.	150.	0.	0.	0.	2000.	2000.

Field No.	Field Name	Format	Columns	Description
Line 1:				
1	TMLOAD	A8	1- 8	Mnemonic name
2	NLS	I8	9-16	Number of load history points
Line 2:				
1	t_i	F8	1- 8	Value of time
2	$T_{l\,1,i}$	F8	9-16	Temperature of ply 1 at time t_i
3	$T_{l\,2,i}$	F8	17-24	Temperature of ply 2 at time t_i
4-10	$T_{l\,3,i} - T_{l\,9,i}$	6(F8)	25-80	Temperature of plies 3 through 9 at time t_i
Line 3:				
1-10	$T_{l\,n,i}$	10(F8)	1-80	Temperature of plies 10 through n at time t_i (see Remark 4)
Line 4:				
1-3	$N_{(x,y,xy),i}$	3(F8)	1-24	Global in-plane force resultant at time t_i
4-6	$M_{(x,y,xy),i}$	3(F8)	25-48	Global in-plane moment resultant at time t_i
7-8	$Q_{(xz,yz),i}$	2(F8)	49-64	Global transverse shear resultant at time t_i
9-10	$P_{(l,u),i}$	2(F8)	65-80	Global lower and upper surface pressure at time t_i

Remarks:

1. There are two alternative forms of the TMLOAD record, which are specified by the sign of NLS.

    (i) A positive NLS defines the loading history as a number of discrete points, record TMLOAD (Generalized Table Form).

    (ii) A negative NLS defines a number of segments to define a piecewise linear loading history, record TMLOAD (Simplified Table Form).

2. Line one, containing the mnemonic TMLOAD, is specified only once in the input data file.

3. Lines two onward are repeated for every discrete point specified (NLS times).

4. The second line of data specifies the time t_i and the temperature of each ply at this time. If there are more than nine plies, the temperatures for the tenth ply onwards can be continued on subsequent lines until all plies are represented.

5. Ply temperatures are restricted to values below the lowest melting temperature of the constituents specified on the MATCRD and INTRFACE records.

6. The last line of data specifies the various mechanical loads applied on the composite at the given instant. The positive sign conventions for the mechanical loads are shown in Section 1.2.5.

7. Default values for the temperatures and mechanical loads are zero.

8. An example of this record, along with a figure, can be found in Case 2 of the sample input data files (Sec. 2.13).

2.12 Input Data Record: TMLOAD (Simplified Table Form)

Description: Defines analysis load history with linear segments

Format and Example:

TMLOAD	NLS	CYCPRO
TMLOAD	-2	PROCESS

t_i	t_{i+1}	INCR	CYCOPT
0.0	300.	35	BEGCYCL UPPER

$T_{l\ 1,i}$	$T_{l\ k,i}$	$T_{l\ n,i}$
1200.	1200.	1200.

$T_{l\ 1,i+1}$	$T_{l\ k,i+1}$	$T_{l\ n,i+1}$
70.	70.	70.

$N_{x,i}$	$N_{y,i}$	$N_{xy,i}$	$M_{x,i}$	$M_{y,i}$	$M_{xy,i}$	$Q_{xz,i}$	$Q_{yz,i}$	$P_{l,i}$	$P_{u,i}$
100.	100.	0.	150.	150.	0.	0.	0.	2000.	2000.

$N_{x,i+1}$	$N_{y,i+1}$	$N_{xy,i+1}$	$M_{x,i+1}$	$M_{y,i+1}$	$M_{xy,i+1}$	$Q_{xz,i+1}$	$Q_{yz,i+1}$	$P_{l,i+1}$	$P_{u,i+1}$
0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

Field No.	Field Name	Format	Columns	Description
Line 1:				
1	TMLOAD	A8	1- 8	Mnemonic name
2	NLS	I8	9-16	Number of load history segments
3			(skip field 3)	
4	CYCPRO	A8	25-32	Alphanumeric to indicate processing when cyclic loads are requested

Line 2:

1	t_i	F8	1- 8	Value of time at t_i
2	t_{i+1}	F8	9-16	Value of time at t_{i+1}
3	INCR	I8	17-24	Number of increments between time t_i and t_{i+1}
4			(skip field 4)	
5	CYCOPT	A16	33-48	Alphanumeric to differentiate between cyclic and static loadings

Line 3:

1	$T_{l\ 1,i}$	F8	1- 8	Temperature of ply 1 at time t_i
2	$T_{l\ 2,i}$	F8	9-16	Temperature of ply 2 at time t_i
3-10	$T_{l\ 3,i} - T_{l\ n,i}$	7(F8)	17-80	Temperature of plies 3 through n at time t_i

Line 4:

1	$T_{l\ 1,i+1}$	F8	1- 8	Temperature of ply 1 at time t_{i+1}
2	$T_{l\ 2,i+1}$	F8	9-16	Temperature of ply 2 at time t_{i+1}
3-10	$T_{l\ 3,i+1} - T_{l\ n,i+1}$	7(F8)	17-80	Temperature of plies 3 through n at time t_{i+1}

Line 5:

1-3	$N_{(x,y,xy),i}$	3(F8)	1-24	Global in-plane force resultant at time t_i
4-6	$M_{(x,y,xy),i}$	3(F8)	25-48	Global in-plane moment resultant at time t_i

| 7-8 | $Q_{(xz,yz),i}$ | 2(F8) | 49-64 | Global transverse shear resultant at time t_i |
| 9-10 | $P_{(l,u),i}$ | 2(F8) | 65-80 | Global lower and upper surface pressure at time t_i |

Line 6:

1-3	$N_{(x,y,xy),i+1}$	3(F8)	1-24	Global in-plane force resultant at time t_{i+1}
4-6	$M_{(x,y,xy),i+1}$	3(F8)	25-48	Global in-plane moment resultant at time t_{i+1}
7-8	$Q_{(xz,yz),i+1}$	2(F8)	49-64	Global transverse shear resultant at time t_{i+1}
9-10	$P_{(l,u),i+1}$	2(F8)	65-80	Global lower and upper surface pressure at time t_{i+1}

Remarks:

1. There are two alternative forms of the TMLOAD record, which are specified by the sign of NLS.

   (i) A positive NLS defines the loading history as a number of discrete points, record TMLOAD (Generalized Table Form).

   (ii) A negative NLS defines a number of segments to define a piecewise linear loading history, record TMLOAD (Simplified Table Form).

2. The maximum value of NLS is -10 for the Simplified Table Form.

3. The field CYCPRO on the first line of data is only required if cumulative mechanical and thermal cycles are specified on the CYCLES record. There are two choices for this field:

      (i) PROCESS   Indicates that processing is simulated in the loading history

      (ii) NOPROCES   Indicates that processing is not considered. This is the default choice.

4. Lines two onward are repeated NLS times.

5. The second line of data specifies the times t_i and t_{i+1}, the number of linear time segments into which the two times are divided, and differentiates between cyclic and static loadings.

6. The field CYCOPT in the second line of data is only required if cumulative mechanical and thermal cycles are specified on the CYCLES record. There are five choices for this field:

      (i)   BEGPROCE   Denotes the beginning of processing

      (ii)   ENDPROCE   Denotes the end of processing

      (iii)   BEGCYCL UPPER   Denotes the initial portion of cycling

      (iv)   ENDCYCL LOWER   Denotes the final portion of cycling

      (v)   ENDCYCL   Denotes the end of cycling

These alphanumerics are required to differentiate between the cyclic and static loads.

7. Ply temperatures are restricted to values below the lowest melting temperature of the constituents specified on the MATCRD and INTRFACE records.

8.   As a general rule in choosing the number of increments (INCR), select INCR such that each subincrement represents a change in temperature of about $35°F$. For example, if $T_{i+1} = 1470°F$ and $T_i = 70°F$, then INCR = $(1470-70)/35 = 40$ increments. If this INCR turns out to be less than 20, set the INCR to 20.

9.   The third line of data specifies the ply temperatures at time t_i. If there are more than ten plies, the temperatures can be continued on as many subsequent lines as necessary. Once all the ply temperatures for time t_i are given, the ply temperatures at time t_{i+1} are specified on the next line of input, in a similar fashion.

10. The last two lines of data specifies the various mechanical loads applied on the composite at times t_i and t_{i+1}, respectively. The positive sign conventions for the mechanical loads are shown in Section 1.1.5.

11. Default values for the temperatures and mechanical loads are zero.

12. A static example of this record can be found in Case 1 of Section 2.13, while a cyclic example can be found in Case 2 of Section 2.13.

2.13   Sample Input Data Files

Three complete input data files, highlighting different features of METCAN are provided below for illustration. The first sample input data file is a more detailed version of the sample problem described in Section 1.2, with each data record discussed in depth. Comment cards are also included throughout the first sample input data file to explain the function of each data record. The second and third sample input data files point out different features of METCAN, but are not presented in the same detail as the first sample input file.

The first sample input data file (Figure 2.13-1) simulates a two ply unidirectional SiC/Ti-15-3 composite under a longitudinal tensile load at room temperature. The first line of the sample input file is the title card. This record contains no mnemonic and can contain any title up to 80 characters long. The second line of the sample input data file is a comment card, denoted by '$' in the first column. Comment cards are inserted before each different record of the sample input data file to briefly describe the function of each record. The next record, containing the mnemonic POST, is used to control the generation of the ten postprocessing files. In the sample input, the 'F' in the second field denotes that these files are not to be generated. The next record (containing the LDDIST mnemonic) controls the load redistribution option in METCAN. Similar to the POST record, the 'F' in the second field specifies that this option is not to be employed. A 'T' in the second field of either the POST or LDDIST records would utilize these options.

The next record begins with the mnemonic PLY. This record consists of five fields and contains information regarding the ply configuration. Fields two through five contain the ply number, the corresponding material system number used in the MATCRD record, the orientation angle of the ply, and the ply thickness, respectively. A separate PLY record is required for each ply in the laminate. For the case depicted in the sample input data file, two PLY records are required since the laminate is composed of two plies. Each ply has an orientation angle of $0°$, a thickness of 0.005 inches, and contains the same materials (represented by the same material system number).

The MATCRD record contains four fields and includes the material details. The second field contains the material system number corresponding to the third

```
--------+--------+--------+--------+--------+--------+--------+--------+--------+--------+
SAMPLE INPUT DATA FOR METCAN, CASE 1

$    No postprocessing files requested.

     POST       F

$    Load redistribution option turned off.

   LDDIST       F

 $   Ply configuration details.

     PLY      1      1     0.0   0.005

     PLY      2      1     0.0   0.005

$    Material details.

   MATCRD       1     .30     0. SICATI15

$    Mechanical and thermal cycling effects.

   CYCLES     1.0    1.0

$    Output requests.

   PRINT     ALL

$    Print output for every load step.

PRINTOPT     ALL

$    Interface details.

INTRFACE       0    .10

$    Simplified table input.

 TMLOAD      -2

$    Start time, end time, and number of increments.

     0.0   1000.      35

$    Temperature in each ply at the beginning and end of the time step.

   1200.   1200.

     70.     70.

$    Mechanical loads at the beginning and end of the time step.

     0.     0.     0.     0.     0.    0.     0.     0.     0.     0.

     0.     0.     0.     0.     0.    0.     0.     0.     0.     0.

$    Start time, end time, and number of increments.

   1000.   2000.      25

$    Temperature in each ply at the beginning and end of the time step.

     70.     70.

     70.     70.

$    Mechanical loads at the beginning and end of the time step.

     0.     0.     0.     0.     0.    0.     0.     0.     0.     0.

   500.     0.     0.     0.     0.    0.     0.     0.     0.     0.
--------+--------+--------+--------+--------+--------+--------+--------+--------+--------+
```

Figure 2.13-1—Sample case 1 input data file.

field of the PLY record. Each existing material system number in the PLY record must have a matching MATCRD record with the same material system number. Fields three through five respectively contain the fiber volume ratio, the void volume ratio, and the fiber and matrix codes used to identify the corresponding entries in the constituent databank. For the sample input data file, this record shows that each ply contains a fiber volume ratio of 0.30, a void volume ratio of 0.0, and is composed of a silicon carbide fiber and a titanium (Ti-15-3) matrix.

The next record begins with the mnemonic CYCLES and is comprised of data regarding thermal and mechanical cycling. Fields two and three specify the number of mechanical and thermal cycles that the laminate is subjected to. A value of 1.0 in either one of these fields nullifies the specified cycling. The sample input data file specifies no mechanical or thermal cycling.

The PRINT and PRINTOPT records are used to tailor the output generation. The 'ALL' in the second field of the PRINT record results in the generation of all the available output. The 'ALL' in the PRINTOPT record defines that the output chosen in the PRINT record is printed at every load/time step of the analysis.

The INTRFACE record is used to define an interface. The value in the second field determines whether an interface is present between the fiber and matrix or a perfect bond exists between the fiber and matrix. A '0' indicates that there is no interface present, while a '1' denotes the presence of an interface. The third field is only used when an interface is present and specifies the thickness of the interface as a fraction of the fiber diameter. This value is

used to identify the interface entry in the constituent databank. For the sample input data file, there is no interface present.

The next record, containing the mnemonic TMLOAD, defines the loading history. The second field, which contains '-2', specifies a linear loading history divided into two segments. The loading history is shown in Figure 2.13-2. Each segment of the loading history is represented by five lines of data which contain time, temperature, and loading conditions. For the first segment, the first line of data consists of three fields which contain the initial and final times for the segment and the number of increments into which the segment is divided. The second line consists of two fields and contains the temperature of each ply at the initial time of the segment, while the third line contains the temperature of each ply at the final segement time. The mechanical loads are specified in lines four and five for the initial and final segment time in a fashion similar to the temperatures. The second segment of the loading history is defined in a similar manner with the same group of five lines. In the sample input data file, the first segment extends from time 0 to 1000 seconds and is divided into 35 increments. Both plies are cooled from 1200°F to 70°F in the absence of any mechanical loads. The second segment continues from 1000 to 2000 seconds and is divided into 25 increments. Each ply is held at a constant temperature of 70°F and a 500 lb/in force resultant is applied in the global x-direction.
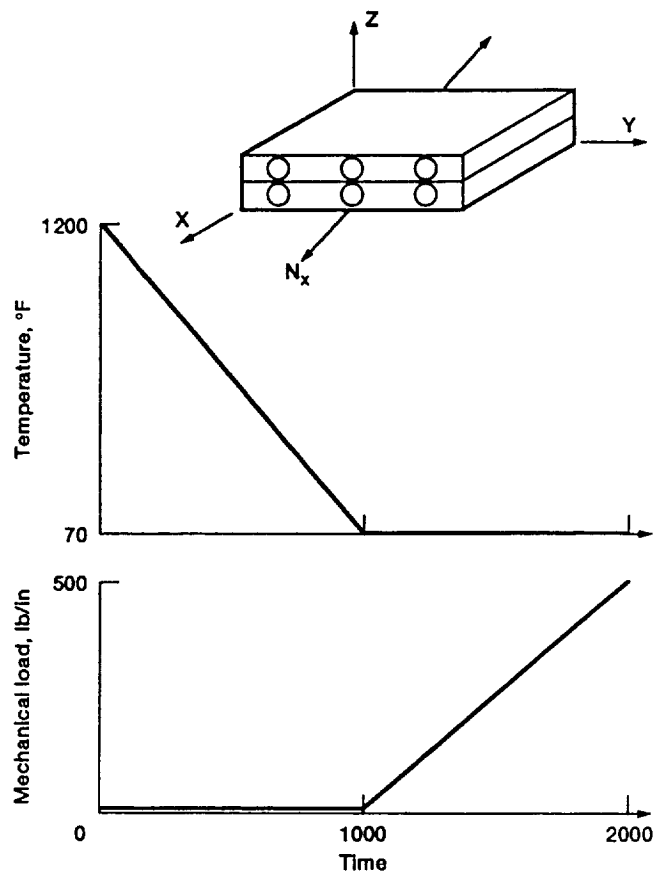
Figure 2.13-2—Sample case 1 loading history: simplified table form for static loading.

The second sample input data file (Figure 2.13-3) models a two ply [90/0] W/Cu composite with a total thickness of 0.20 inches and a fiber volume ratio of 0.35. Postprocessing files are requested and the load redistribution option is not in effect. Mechanical and thermal cycling is turned off. Three output options are requested, 1) information regarding the current load/time step, 2) laminate stress-strain relationships, and 3) constituent microstresses and microstrains. The output is reported after every fifth time step. An interface with a thickness of 2% of the fiber diameter is specified. The generalized table form is used to define the loading history in two discrete points as shown in Figure 2.13-4. The first point is defined at time 0 seconds, with the temperature of both plies set to 1500 F and a stress resultant of 1000 lb/in applied in the global x-direction. The second point occurs at time 500 seconds, the temperature of the two plies is reduced to 700 F and the stress resultant in the x-direction is decreased to 800 lb/in. For simplicity, only two points are defined in this example. Generally for the loading history shown, many more points would be required to accurately model the loading history.

```
--------+--------+--------+--------+--------+--------+--------+--------+--------+--------+

SAMPLE INPUT DATA FOR METCAN, CASE 2

    POST      T

   LDDIST     F

     PLY      1      1    90.    0.010

     PLY      2      1     0.    0.010

   MATCRD     1     .35    0. TUNGCOPR

   CYCLES    1.0    1.0 1.0E+06 4.0E+02 1.0E+06 4.0E+02 1.0E+06 4.0E+02

   PRINT  LDSTEP

   PRINT  STRSTRN

   PRINT   MICRO

 PRINTOPT    5

 INTRFACE    1    .02

   TMLOAD     2

    0.0    1500.  1500.

   1000.     0.     0.     0.     0.     0.     0.     0.     0.     0.

    500.   700.   700.

    500.     0.     0.     0.     0.     0.     0.     0.     0.     0.

--------+--------+--------+--------+--------+--------+--------+--------+--------+--------+
```

Figure 2.13-3—Sample case 2 input data file.
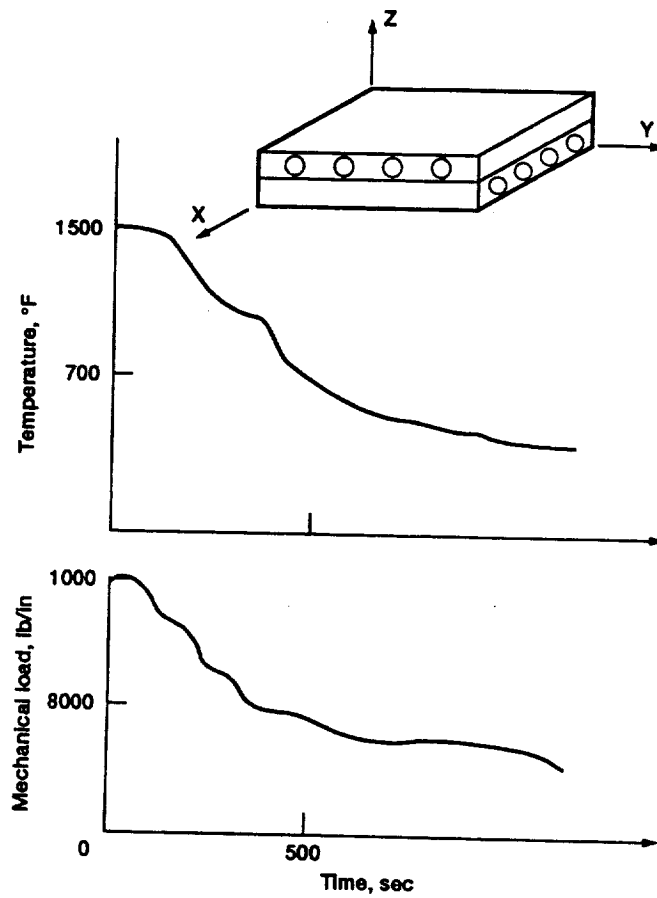
Figure 2.13-4—Sample case 2 loading history: generalized table form for static loading.

The third sample input data file (Figure 2.13-5) corresponds to the first sample case with the addition of mechanical and thermal cycling as shown in Figure 2.13-6. The addition of cycling is reflected in the CYCLES and TMLOAD records. The CYCLES record specifies 750,000 mechanical load cycles and 300 thermal load cycles. The TMLOAD record defines a piecewise linear loading history divided into four segments and indicates that processing will be simulated in the loading history. The first segment ranges from time 0 to 1000 seconds and is divided into 35 time steps. The alphanumeric BEGPROCE denotes that the first segment simulates the processing of the composite by cooling down from 1200°F to 70°F in the absence of mechanical loads. The second segment ranges from 1000 to 2000 seconds and is composed of 25 time steps. The BEGCYCL UPPER alphanumeric denotes that this segment is the initial portion of the cyclic loading, which is composed of a heat up from 70°F to 1000°F with the addition of a 250 lb/in force resultant in the global x-direction. The third segment spans time 2000 to 3000 seconds and is split into 25 time steps. The alphanumeric ENDCYCL LOWER indicates that this segment is the final portion of the cyclic loading, which consists of a cool down from 1000°F to 70°F and an unloading of the force resultant in the global x-direction from 250 lb/in to zero. The fourth segment begins at 3000 seconds and ends at 4000 seconds. It is divided into 25 time steps and the alphanumeric ENDCYCL indicates that this segment is not to be cycled. The loading for this segment consists the application of a 500 lb/in force resultant in the global x-direction at a constant temperature of 70°F.

```
-------+-------+-------+-------+-------+--------+-------+-------+-------+-------+
SAMPLE INPUT DATA FOR METCAN, CASE 3

     POST       F

   LDDIST       F

      PLY       1      1     0.0    0.005

      PLY       2      1     0.0    0.005

   MATCRD       1    .30    0. SICATI15

   CYCLES 7.5E+05 3.0E+02 1.0E+06 4.0E+02 1.0E+06 4.0E+02 1.0E+06 4.0E+02

    PRINT     ALL

 PRINTOPT     ALL

  INTRFACE      0    .10

    TMLOAD     -4        PROCESS

      0.0   1000.    35        BEGPROCE

     1200.   1200.

       70.     70.

        0.      0.     0.     0.     0.     0.     0.     0.     0.     0.

        0.      0.     0.     0.     0.     0.     0.     0.     0.     0.

     1000.   2000.    25        BEGCYCL UPPER

       70.     70.

     1000.   1000.

        0.      0.     0.     0.     0.     0.     0.     0.     0.     0.

      250.      0.     0.     0.     0.     0.     0.     0.     0.     0.

     2000.   3000.    25        ENDCYCL LOWER

     1000.   1000.

       70.     70.

      250.      0.     0.     0.     0.     0.     0.     0.     0.     0.

        0.      0.     0.     0.     0.     0.     0.     0.     0.     0.

     3000.   4000.    25        ENDCYCL

       70.     70.

       70.     70.

        0.      0.     0.     0.     0.     0.     0.     0.     0.     0.

      500.      0.     0.     0.     0.  ·  0.     0.     0.     0.     0.

-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```

Figure 2.13-5—Sample case 3 input data file.
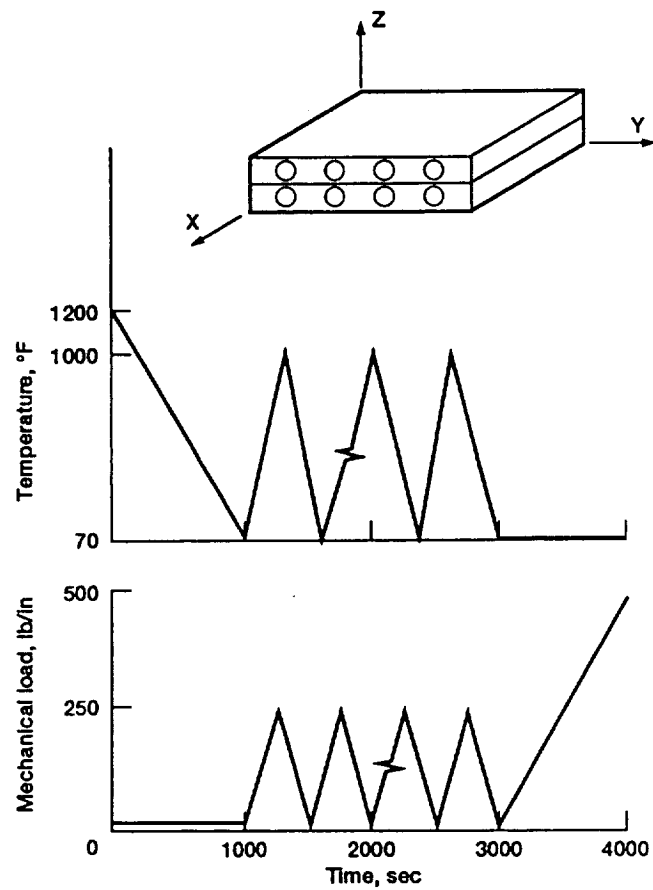
Figure 2.13-6—Sample case 3 loading history: simplified table form for cyclic loading.

Section 3.0 Table of Contents

3.0 Constituent Databank

The databank is organized into three sections with each section containing a set number of records in a predefined order. The first section contains the fiber properties and contains nine records. The second section arranges the matrix properties into ten records, while the third section contains the interphase properties on nine records. Each record is composed of one or more lines of data with a varying format from record to record. Note that the format for the constituent databank records is different from the fixed format employed in the primary input file. Each line of data begins with a mnemonic. Character, integer, and exponential formats must be right justified, while the floating point format can fall anywhere in the appropriate field. The various constituent properties input into the databank are room temperature values. A sample constituent databank is presented at the end of the section for illustration.

3.1.1   Fiber Data Record: CODE

Description: Defines fiber code name

Format and Example:

```
---+----------------------------------------------------------------------+

CODE      COMMENT
---+----------------------------------------------------------------------+

SICA      Optional description of fiber

---+----------------------------------------------------------------------+
```

Field No.	Field Name	Format	Columns	Description
1	CODE	A4	1-4	Fiber code name
2	COMMENT	A76	5-80	Optional description of fiber

Remarks:

1.   The CODE for each fiber in the databank must be unique.

3.1.2   Fiber Data Record: FP

Description: Defines fiber physical properties

Format and Example:

```
-+------+---------+---------+---------+------------------------------------
FP     N_f      D_f        ρ_f        T_Mf
-+------+---------+---------+---------+------------------------------------
FP     1  .560E-02  .110E+00  .487E+04
-+------+---------+---------+---------+------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	FP	A2	1-2	Mnemonic name
2	N_f	I5	4-9	Number of fibers per bundle
3	D_f	E10.3	10-19	Fiber diameter
4	ρ_f	E10.3	20-29	Fiber weight density
5	T_{Mf}	E10.3	30-39	Fiber melting temperature

3.1.3 Fiber Data Record: FE

Description: Defines fiber elastic properties

Format and Example:

```
-+----------+---------+---------+---------+---------+---------+----------------

FE      E_f11      E_f22      v_f12      v_f23      G_f12      G_f23
-+----------+---------+---------+---------+---------+---------+----------------

FE   .620E+08   .620E+08   .300E+00   .300E+00   .238E+08   .238E+08
-+----------+---------+---------+---------+---------+---------+----------------
```

Field No.	Field Name	Format	Columns	Description
1	FE	A2	1-2	Mnemonic name
2	E_{f11}	E10.3	4-13	Fiber longitudinal modulus
3	E_{f22}	E10.3	14-23	Fiber transverse modulus
4	ν_{f12}	E10.3	24-33	Fiber Poisson's ratio
5	ν_{f23}	E10.3	34-43	Fiber Poisson's ratio
6	G_{f12}	E10.3	44-53	Fiber in-plane shear modulus
7	G_{f23}	E10.3	54-63	Fiber out-of-plane shear modulus

3.1.4   Fiber Data Record: FT

<u>Description</u>:   Defines fiber thermal properties

<u>Format</u> <u>and</u> <u>Example</u>:

```
-+----------+---------+---------+---------+---------+------------------------
FT     α        α        K        K        C
        f11      f22      f11      f22      pf
-+----------+---------+---------+---------+---------+------------------------
FT   .180E-05  .180E-05  .750E+00  .750E+00  .290E+00
-+----------+---------+---------+---------+---------+------------------------
```

<u>Field</u> <u>No</u>.	<u>Field</u> <u>Name</u>	<u>Format</u>	<u>Columns</u>	<u>Description</u>
1	FT	A2	1-2	Mnemonic name
2	α_{f11}	E10.3	4-13	Fiber longitudinal coefficient of thermal expansion
3	α_{f22}	E10.3	14-23	Fiber transverse coefficient of thermal expansion
4	K_{f11}	E10.3	24-33	Fiber longitudinal thermal conductivity
5	K_{f22}	E10.3	34-43	Fiber transverse thermal conductivity
6	C_{pf}	E10.3	44-53	Fiber heat capacity

3.1.5 Fiber Data Record: FS

Description: Defines fiber strength allowables

Format and Example:

```
-+----------+---------+---------+---------+---------+---------+----------------
FS    S_f11T    S_f11C    S_f22T    S_f22C    S_f12    S_f23
-+----------+---------+---------+---------+---------+---------+----------------
FS   .500E+06  .650E+06  .500E+06  .650E+06  .300E+06  .300E+06
-+----------+---------+---------+---------+---------+---------+----------------
```

Field No.	Field Name	Format	Columns	Description
1	FS	A2	1-2	Mnemonic name
2	S_{f11T}	E10.3	4-13	Fiber longitudinal tensile strength
3	S_{f11C}	E10.3	14-23	Fiber longitudinal compressive strength
4	S_{f22T}	E10.3	24-33	Fiber transverse tensile strength
5	S_{f22C}	E10.3	34-43	Fiber transverse compressive strength
6	S_{f12}	E10.3	44-53	Fiber in-plane shear strength
7	S_{f23}	E10.3	54-63	Fiber out-of-plane shear strength

Remarks:

1. In cases where only the experimental tensile strength is available, the following approximate values are used for the compressive and shear strengths:

$$S_C = S_T \qquad \text{and} \qquad S_S = 0.6\ S_T$$

3.1.6   Fiber Data Record: SIGFO

Description: Defines reference values of fiber stress

Format and Example:

```
----+--------------+---------+---------+---------+---------+--------------------
SIGFO      σ_f11       σ_f22     σ_f12     σ_f23     σ_f13     σ_f33
----+--------------+---------+---------+---------+---------+--------------------
SIGFO      0.          0.        0.        0.        0.        0.
----+--------------+---------+---------+---------+---------+--------------------
```

Field No.	Field Name	Format	Columns	Description
1	SIGFO	A5	1-5	Mnemonic name
2	σ_{f11}	E10.3	11-20	Reference longitudinal stress value
3	σ_{f22}	E10.3	21-30	Reference transverse stress value
4	σ_{f12}	E10.3	31-40	Reference in-plane shear stress value
5	σ_{f23}	E10.3	41-50	Reference out-of-plane shear stress value
6	σ_{f13}	E10.3	51-60	Reference out-of-plane shear stress value
7	σ_{f33}	E10.3	61-70	Reference through the thickness stress value

<u>Remarks</u>:

1. The reference values of stress are used in the stress term of the multifactor interaction relationship and are typically set to zero for convenience.

3.1.7 Fiber Data Record: DOTFO

Description: Defines reference values of fiber stress rate

Format and Example:

```
----+--------------+---------+---------+---------+---------+-------------------
SIGFO       σ̇f11      σ̇f22      σ̇f12      σ̇f23      σ̇f13      σ̇f33
----+--------------+---------+---------+---------+---------+-------------------
SIGFO       0.        0.        0.        0.        0.        0.
----+--------------+---------+---------+---------+---------+-------------------
```

Field No.	Field Name	Format	Columns	Description
1	SIGFO	A5	1-5	Mnemonic name
2	$\dot\sigma_{f11}$	E10.3	11-20	Reference longitudinal stress rate value
3	$\dot\sigma_{f22}$	E10.3	21-30	Reference transverse stress rate value
4	$\dot\sigma_{f12}$	E10.3	31-40	Reference in-plane shear stress rate value
5	$\dot\sigma_{f23}$	E10.3	41-50	Reference out-of-plane shear stress rate value
6	$\dot\sigma_{f13}$	E10.3	51-60	Reference out-of-plane shear stress rate value
7	$\dot\sigma_{f33}$	E10.3	61-70	Reference through the thickness stress rate value

<u>Remarks</u>:

1. The reference values of stress rates are used in the stress rate term of the multifactor interaction relationship and are typically set to zero for convenience.

3.1.8   Fiber Data Record: EXPONENTS

<u>Description</u>:   Defines values of exponents in the multifactor interaction

      relationship

<u>Format</u> <u>and</u> <u>Example</u>:

```
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS  FEX1   FEX2   FEX3   FEX4   FEX5   FEX6   FEX7   FEX8   FEX9  FEX10
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS  0.25   0.25   0.25   0.25   0.25   0.00   0.25   0.25   0.25   0.25
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS FEX11 FEX12 FEX13 FEX14 FEX15 FEX16 FEX17 FEX18 FEX19 FEX20
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS  0.25   0.25   0.25   0.25   0.00   0.25   0.25   0.00   0.25   0.25
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS FEX21 FEX22 FEX23 FEX24 FEX25 FEX26 FEX27 FEX28 FEX29 FEX30
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS  0.25   0.25   0.25   0.25   0.25   0.25   0.25   0.25   0.25   0.25
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS FEX31
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
EXPONENTS  0.25
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
```

Field No.	Field Name	Format	Columns	Description

Line 1:

Field No.	Field Name	Format	Columns	Description
1	EXPONENTS	A9	1-9	Mnemonic name
2	FEX1	F5.2	11-15	Reserved for future use
3	FEX2	F5.2	17-21	Modulus-stress rate exponent
4	FEX3	F5.2	23-27	Modulus-stress exponent
5	FEX4	F5.2	29-33	Modulus-temperature exponent
6	FEX5	F5.2	35-39	Strength-stress rate exponent
7	FEX6	F5.2	41-45	Strength-stress exponent
8	FEX7	F5.2	47-51	Strength-temperature exponent
9	FEX8	F5.2	53-57	Poisson's ratio-stress rate exponent
10	FEX9	F5.2	59-63	Poisson's ratio-stress exponent
11	FEX10	F5.2	65-69	Poisson's ratio-temperature exponent

Line 2:

Field No.	Field Name	Format	Columns	Description
1	EXPONENTS	A9	1-9	Mnemonic name
2	FEX11	F5.2	11-15	Reserved for future use
3	FEX12	F5.2	17-21	Reserved for future use
4	FEX13	F5.2	23-27	Reserved for future use
5	FEX14	F5.2	29-33	Heat conductivity-stress rate exponent
6	FEX15	F5.2	35-39	Heat conductivity-stress exponent
7	FEX16	F5.2	41-45	Heat conductivity-temperature exponent
8	FEX17	F5.2	47-51	CTE-stress rate exponent

9	FEX18	F5.2	53-57	CTE-stress rate exponent
10	FEX19	F5.2	59-63	CTE-temperature exponent
11	FEX20	F5.2	65-69	Reserved for future use

Line 3:

1	EXPONENTS	A9	1-9	Mnemonic name
2	FEX21	F5.2	11-15	Reserved for future use
3	FEX22	F5.2	17-21	Reserved for future use
4	FEX23	F5.2	23-27	Reserved for future use
5	FEX24	F5.2	29-33	Reserved for future use
6	FEX25	F5.2	35-39	Reserved for future use
7	FEX26	F5.2	41-45	Reserved for future use
8	FEX27	F5.2	47-51	Reserved for future use
9	FEX28	F5.2	53-57	Reserved for future use
10	FEX29	F5.2	59-63	Reserved for future use
11	FEX30	F5.2	65-69	Reserved for future use

Line 4:

1	EXPONENTS	A9	1-9	Mnemonic name
2	FEX31	F5.2	11-15	Reserved for future use

<u>Remarks</u>:

1. The various exponents listed are used in the multifactor interaction equation (Section 1.6.1). For example FEX4 would be the exponent used to determine the temperature effect on the fiber modulus.

$$\frac{E_{f11}}{E_{f11o}} = \left[\frac{T_{Mf} - T}{T_{Mf} - T_o} \right]^{FEX4} \ldots \ldots$$

2. The values of the exponents listed above represent the default values.

3. The locations of the currently used exponents are shown below for convenient reference.

	Exponent Field Name (i.e. FEX__)		
Property	Stress Rate	Stress	Temperature
Modulus	2	3	4
Strength	5	6	7
Poisson's Ratio	8	9	10
Heat Conductivity	14	15	16
Coeff. of Thermal Exp.	17	18	19

All other locations are reserved for future use.

3.1.9   Fiber Data Record: OVER

Description: Defines the end of the fiber section in the databank

Format:

```
------------------------------------------------------------------------

OVER END OF FIBER PROPERTIES
------------------------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	OVER...	A28	1-28	Mnemonic name

Remarks:

1.   This record is used to differentiate between the fiber and matrix sections of the databank. This record is only inserted after the last fiber entry.

3.2.1   Matrix Data Record: CODE

Description: Defines matrix code name

Format and Example:

```
---+-----------------------------------------------------------------------

CODE      COMMENT

---+-----------------------------------------------------------------------

TI15      Optional description of matrix

---+-----------------------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	CODE	A4	1-4	Matrix code name
2	COMMENT	A76	5-80	Optional description of matrix

Remarks:

1.   The CODE for each matrix in the databank must be unique.

3.2.2   Matrix Data Record: MP

Description: Defines matrix physical properties

Format and Example:

```
-+----------+-----------------------------------------------------------------

MP       ρ
          m
-+----------+-----------------------------------------------------------------

MP   .172E+00
-+----------+-----------------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	FP	A2	1-2	Mnemonic name
3	D_f	E10.3	4-13	Matrix weight density

3.2.3   Matrix Data Record: ME

Description: Defines matrix elastic properties

Format and Example:


```
-+----------+----------+----------+-----------------------------------------------

ME      E           ν          α           .
         m           m          m
-+----------+----------+----------+-----------------------------------------------

ME    .123E+08   .320E+00   .450E-05

-+----------+----------+----------+-----------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	ME	A2	1-2	Mnemonic name
2	E_m	E10.3	4-13	Matrix modulus
3	ν_m	E10.3	14-23	Matrix Poisson's ratio
4	α_m	E10.3	24-33	Matrix coefficient of thermal expansion

3.2.4   Matrix Data Record: MT

Description: Defines matrix thermal properties

Format and Example:

```
-+----------+---------+-------------------------------------------------------

MT      K       C
         m       pm
-+----------+---------+-------------------------------------------------------

MT    .390E+00 .120E +00

-+----------+---------+-------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	MT	A2	1-2	Mnemonic name
2	K_m	E10.3	4-13	Matrix thermal conductivity
3	C_{pm}	E10.3	14-23	Matrix heat capacity

3.2.5   Matrix Data Record: MS

Description: Defines matrix strength properties

Format and Example:


```
-+----------+---------+---------+---------+---------+---------+---------+-------
MS    S_mT      S_mC      S_mS      ε_mT      ε_mC      ε_mS      ε_mτ
-+----------+---------+---------+---------+---------+---------+---------+-------
MS   .130E+06  .130E+06  .780E+05  .120E+00  .120E+00  .120E+00  .120E+00
-+----------+---------+---------+---------+---------+---------+---------+-------
```

Field No.	Field Name	Format	Columns	Description
1	MS	A2	1-2	Mnemonic name
2	S_{mT}	E10.3	4-13	Matrix tensile strength
3	S_{mC}	E10.3	14-23	Matrix compressive strength
4	S_{mS}	E10.3	24-33	Matrix shear strength
5	ε_{mT}	E10.3	34-43	Matrix tensile strain
6	ε_{mC}	E10.3	44-53	Matrix compressive strain
7	ε_{mS}	E10.3	54-63	Matrix shear strain
8	$\varepsilon_{m\tau}$	E10.3	64-73	Matrix torsional strain

Remarks:

1.   In cases where only the experimental tensile strength is available, the
     following approximate values are used for the compressive and shear
     strengths:

$$S_C = S_T \quad \text{and} \quad S_S = 0.6\, S_T$$

3.2.6   Matrix Data Record: MV

Description: Defines additional matrix thermal properties

Format and Example:

```
-+----------+---------+-------------------------------------------------
MV      K          T
         V          Mm
-+----------+---------+-------------------------------------------------
MV    .019E+OO .18OE +04
-+----------+---------+-------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	MV	A2	1-2	Mnemonic name
2	K_v	E10.3	4-13	Matrix void thermal conductivity
3	T_{Mm}	E10.3	14-23	Matrix melting temperature

3.2.7   Matrix Data Record: SIGMO

Description: Defines reference values of matrix stresses

Format and Example:

```
----+--------------+---------+---------+---------+---------+---------+--------+
SIGMO    σ_m11A      σ_m22A    σ_m22B    σ_m22C    σ_m12A    σ_m12B    σ_m12C
----+--------------+---------+---------+---------+---------+---------+--------+
SIGMO    0.0         0.0       0.0       0.0       0.0       0.0       0.0
----+--------------+---------+---------+---------+---------+---------+---------+


----+--------------+---------+---------+---------+---------+---------+---------+
SIGMO    σ_m23A      σ_m23B    σ_m23C    σ_m13A    σ_m13B    σ_m13C    σ_m33A
----+--------------+---------+---------+---------+---------+---------+---------+
SIGMO    0.0         0.0       0.0       0.0       0.0       0.0       0.0
----+--------------+---------+---------+---------+---------+---------+---------+


----+--------------+---------+---------+---------+---------+---------+---------+
SIGMO    σ_m33B      σ_m33C    σ_m11B    σ_m11C
----+--------------+---------+---------+---------+---------+---------+---------+
SIGMO    0.0         0.0       0.0       0.0
----+--------------+---------+---------+---------+---------+---------+---------+
```

Field No.	Field Name	Format	Columns	Description

Line 1:

1	SIGMO	A5	1-5	Mnemonic name
2	σ_{m11A}	E10.3	11-20	Reference stress in region m11A
3	σ_{m22A}	E10.3	21-30	Reference stress in region m22A
4	σ_{m22B}	E10.3	31-40	Reference stress in region m22B

5	σ_{m22C}	E10.3	41-50	Reference stress in region m22C
6	σ_{m12A}	E10.3	51-60	Reference stress in region m12A
7	σ_{m12B}	E10.3	61-70	Reference stress in region m12B
8	σ_{m12C}	E10.3	71-80	Reference stress in region m12C

Line 2:

1	SIGMO	A5	1-5	Mnemonic name
2	σ_{m23A}	E10.3	11-20	Reference stress in region m23A
3	σ_{m23B}	E10.3	21-30	Reference stress in region m23B
4	σ_{m23C}	E10.3	31-40	Reference stress in region m23C
5	σ_{m13A}	E10.3	41-50	Reference stress in region m13A
6	σ_{m13B}	E10.3	51-60	Reference stress in region m13B
7	σ_{m13C}	E10.3	61-70	Reference stress in region m13C
8	σ_{m33A}	E10.3	71-80	Reference stress in region m33A

Line 3:

1	SIGMO	A5	1-5	Mnemonic name
2	σ_{m33B}	E10.3	11-20	Reference stress in region m33B
3	σ_{m33C}	E10.3	21-30	Reference stress in region m33C
4	σ_{m11B}	E10.3	31-40	Reference stress in region m11B
5	σ_{m11C}	E10.3	41-50	Reference stress in region m11C

Remarks:

1. The reference values of stress are used in the stress term of the multifactor interaction relationship and are typically set to zero for convenience.

3.2.8   Matrix Data Record: DOTMO

<u>Description</u>:   Defines reference values of matrix stress rates

<u>Format</u> <u>and</u> <u>Example</u>:

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | $\dot{\sigma}_{m11A}$ | $\dot{\sigma}_{m22A}$ | $\dot{\sigma}_{m22B}$ | $\dot{\sigma}_{m22C}$ | $\dot{\sigma}_{m12A}$ | $\dot{\sigma}_{m12B}$ | $\dot{\sigma}_{m12C}$ |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | $\dot{\sigma}_{m23A}$ | $\dot{\sigma}_{m23B}$ | $\dot{\sigma}_{m23C}$ | $\dot{\sigma}_{m13A}$ | $\dot{\sigma}_{m13B}$ | $\dot{\sigma}_{m13C}$ | $\dot{\sigma}_{m33A}$ |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | $\dot{\sigma}_{m33B}$ | $\dot{\sigma}_{m33C}$ | $\dot{\sigma}_{m11B}$ | $\dot{\sigma}_{m11C}$ | | | |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

| DOTMO | 0.0 | 0.0 | 0.0 | 0.0 | | | |

```
----+-------------+---------+---------+---------+---------+---------+---------+
```

<u>Field</u> <u>No</u>.	<u>Field</u> <u>Name</u>	<u>Format</u>	<u>Columns</u>	<u>Description</u>

Line 1:

1	DOTMO	A5	1-5	Mnemonic name
2	$\dot{\sigma}_{m11A}$	E10.3	11-20	Reference stress rate in region m11A
3	$\dot{\sigma}_{m22A}$	E10.3	21-30	Reference stress rate in region m22A

4	$\dot{\sigma}_{m22B}$	E10.3	31-40	Reference stress rate in region m22B
5	$\dot{\sigma}_{m22C}$	E10.3	41-50	Reference stress rate in region m22C
6	$\dot{\sigma}_{m12A}$	E10.3	51-60	Reference stress rate in region m12A
7	$\dot{\sigma}_{m12B}$	E10.3	61-70	Reference stress rate in region m12B
8	$\dot{\sigma}_{m12C}$	E10.3	71-80	Reference stress rate in region m12C

Line 2:

1	DOTMO	A5	1-5	Mnemonic name
2	$\dot{\sigma}_{m23A}$	E10.3	11-20	Reference stress rate in region m23A
3	$\dot{\sigma}_{m23B}$	E10.3	21-30	Reference stress rate in region m23B
4	$\dot{\sigma}_{m23C}$	E10.3	31-40	Reference stress rate in region m23C
5	$\dot{\sigma}_{m13A}$	E10.3	41-50	Reference stress rate in region m13A
6	$\dot{\sigma}_{m13B}$	E10.3	51-60	Reference stress rate in region m13B
7	$\dot{\sigma}_{m13C}$	E10.3	61-70	Reference stress rate in region m13C
8	$\dot{\sigma}_{m33A}$	E10.3	71-80	Reference stress rate in region m33A

Line 3:

1	DOTMO	A5	1-5	Mnemonic name
2	$\dot{\sigma}_{m33B}$	E10.3	11-20	Reference stress rate in region m33B
3	$\dot{\sigma}_{m33C}$	E10.3	21-30	Reference stress rate in region m33C
4	$\dot{\sigma}_{m11B}$	E10.3	31-40	Reference stress rate in region m11B
5	$\dot{\sigma}_{m11C}$	E10.3	41-50	Reference stress rate in region m11C

<u>Remarks</u>:

1. The reference values of stress rates are used in the stress rate term of the multifactor interaction relationship and are typically set to zero for convenience.

3.2.9   Matrix Data Record: EXPONENTS

<u>Description</u>:   Defines values of exponents for matrix properties in the

multifactor interaction relationship

<u>Format</u> <u>and</u> <u>Example</u>:

```
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS  MEX1  MEX2  MEX3  MEX4  MEX5  MEX6  MEX7  MEX8  MEX9 MEX10

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS MEX11 MEX12 MEX13 MEX14 MEX15 MEX16 MEX17 MEX18 MEX19 MEX20

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.00  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS MEX21 MEX22 MEX23 MEX24 MEX25 MEX26 MEX27 MEX28 MEX29 MEX30

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS MEX31

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------

EXPONENTS  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------
```

Field No.	Field Name	Format	Columns	Description

Line 1:

1	EXPONENTS	A9	1-9	Mnemonic name
2	MEX1	F5.2	11-15	Reserved for future use
3	MEX2	F5.2	17-21	Modulus-stress rate exponent
4	MEX3	F5.2	23-27	Modulus-stress exponent
5	MEX4	F5.2	29-33	Modulus-temperature exponent
6	MEX5	F5.2	35-39	Strength-stress rate exponent
7	MEX6	F5.2	41-45	Strength-stress exponent
8	MEX7	F5.2	47-51	Strength-temperature exponent
9	MEX8	F5.2	53-57	Poisson's ratio-stress rate exponent
10	MEX9	F5.2	59-63	Poisson's ratio-stress exponent
11	MEX10	F5.2	65-69	Poisson's ratio-temperature exponent

Line 2:

1	EXPONENTS	A9	1-9	Mnemonic name
2	MEX11	F5.2	11-15	Reserved for future use
3	MEX12	F5.2	17-21	Reserved for future use
4	MEX13	F5.2	23-27	Reserved for future use
5	MEX14	F5.2	29-33	Heat conductivity-stress rate exponent
6	MEX15	F5.2	35-39	Heat conductivity-stress exponent
7	MEX16	F5.2	41-45	Heat conductivity-temperature exponent
8	MEX17	F5.2	47-51	CTE-stress rate exponent

9	MEX18	F5.2	53-57	CTE-stress rate exponent
10	MEX19	F5.2	59-63	CTE-temperature exponent
11	MEX20	F5.2	65-69	Reserved for future use

Line 3:

1	EXPONENTS	A9	1-9	Mnemonic name
2	MEX21	F5.2	11-15	Reserved for future use
3	MEX22	F5.2	17-21	Reserved for future use
4	MEX23	F5.2	23-27	Reserved for future use
5	MEX24	F5.2	29-33	Reserved for future use
6	MEX25	F5.2	35-39	Reserved for future use
7	MEX26	F5.2	41-45	Reserved for future use
8	MEX27	F5.2	47-51	Reserved for future use
9	MEX28	F5.2	53-57	Reserved for future use
10	MEX29	F5.2	59-63	Reserved for future use
11	MEX30	F5.2	65-69	Reserved for future use

Line 4:

| 1 | EXPONENTS | A9 | 1-9 | Mnemonic name |
| 2 | MEX31 | F5.2 | 11-15 | Reserved for future use |

Remarks:

1. The various exponents listed are used in the multifactor interaction equation. For example MEX3 would be the exponent used to determine the stress effect on the matrix modulus.

$$\frac{E_{m11}}{E_{m11_o}} = \left[\frac{S_{m11} - \sigma_{m11}}{S_{m11} - \sigma_{m11_o}} \right]^{MEX3} \cdots$$

2. The values of the exponents listed above represent the default values.

3. The locations of the currently used exponents are shown below for convenient reference.

Property	Exponent Field Name (i.e. MEX__)		
	Stress Rate	Stress	Temperature
Modulus	2	3	4
Strength	5	6	7
Poisson's Ratio	8	9	10
Heat Conductivity	14	15	16
Coeff. of Thermal Exp.	17	18	19

All other locations are reserved for future use.

3.2.10   Matrix Data Record: OVER

Description: Defines the end of the matrix section in the databank

Format:

```
-----------------------------------------------------------------------

OVER END OF MATRIX PROPERTIES

-----------------------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	OVER...	A28	1-28	Mnemonic name

Remarks:

1.   This record is used to differentiate between the matrix and interphase sections of the databank. This record is inserted only after the last matrix entry.

3.3.1   Interphase Data Record: (No Mnemonic)

Description: Defines optional interphase description

Format and Example:


```
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
TITLE
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
Description of interphase
-------+-------+-------+-------+-------+-------+-------+-------+-------+-------+
```


Field No.	Field Name	Format	Columns	Description
1	TITLE	A80	1-80	Interphase description

Remarks:

1.   Unlike the fiber and matrix, which are distinguished by their code names,
      the interphases are defined by their thickness (see DP record).

3.3.2　　Interphase Data Record:　DP

Description:　Defines interphase physical properties

Format and Example:

```
-+----------+---------+----------------------------------------------
DP     ρd        td
-+----------+---------+----------------------------------------------
DP    .172E+00  .020E+00
-+----------+---------+----------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	DP	A2	1-2	Mnemonic name
2	ρ_d	E10.3	4-13	Interphase weight density
3	t_d	E10.3	14-23	Interphase thickness

Remarks:

1.　The input data file uses the interface thickness to select the desired interphase.　This means that the thickness of the desired interphase must be unique.

3.3.3   Interphase Data Record: DE

Description: Defines interphase elastic properties

Format and Example:

```
-+----------+---------+---------+----------------------------------------
DE    E_d       ν_d       α_d
-+----------+---------+---------+----------------------------------------
DE   .300E+07  .320E+00  .450E-05
-+----------+---------+---------+----------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	DE	A2	1-2	Mnemonic name
2	E_d	E10.3	4-13	Interphase modulus
3	ν_d	E10.3	14-23	Interphase poisson's ratio
4	α_d	E10.3	24-33	Interphase coefficient of thermal expansion

3.3.4   Interphase Data Record: DT

Description: Defines interphase thermal properties

Format and Example:

```
-+----------+---------+------------------------------------------------------
DT      K_d        C_pd
-+----------+---------+------------------------------------------------------
DT    .390E+00   .120E+00
-+----------+---------+------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	DT	A2	1-2	Mnemonic name
2	K_d	E10.3	4-13	Interphase thermal conductivity
3	C_{pd}	E10.3	14-23	Interphase heat capacity

3.3.5   Interphase Data Record: DS

Description: Defines interphase strength properties

Format and Example:

```
-+----------+----------+---------+----------+----------+----------+----------+-------
DS    S        S        S        ε        ε        ε        ε
       dT       dC       dS        dT       dC       dS       dτ
-+----------+----------+---------+----------+----------+----------+----------+-------
DS   .325E+05  .325E+05  .195E+05  .120E+00  .120E+00  .120E+00  .120E+00
-+----------+----------+---------+----------+----------+----------+----------+-------
```

Field No.	Field Name	Format	Columns	Description
1	DS	A2	1-2	Mnemonic name
2	S_{dT}	E10.3	4-13	Interphase tensile strength
3	S_{dC}	E10.3	14-23	Interphase compressive strength
4	S_{dS}	E10.3	24-33	Interphase shear strength
5	ε_{dT}	E10.3	34-43	Interphase tensile strain
6	ε_{dC}	E10.3	44-53	Interphase compressive strain
7	ε_{dS}	E10.3	54-63	Interphase shear strain
8	$\varepsilon_{d\tau}$	E10.3	64-73	Interphase torsional strain

Remarks:

1.   In cases where only the experimental tensile strength is available, the following approximate values are used for the compressive and shear strengths:

$$S_C = S_T \qquad \text{and} \qquad S_S = 0.6\ S_T$$

3.3.6   Interphase Data Record: DV

Description: Defines additional interphase thermal properties

Format and Example:

```
-+----------+---------+------------------------------------------------------

DV      K_v        T_Md
-+----------+---------+------------------------------------------------------

DV   .019E+00  .180E+04
-+----------+---------+------------------------------------------------------
```

Field No.	Field Name	Format	Columns	Description
1	DV	A2	1-2	Mnemonic name
2	K_v	E10.3	4-13	Interphase void thermal conductivity
3	T_{Md}	E10.3	14-23	Interphase melting temperature

3.3.7   Interphase Data Record: SIGDO

<u>Description</u>:   Defines reference values of interphase stresses

<u>Format</u> <u>and</u> <u>Example</u>:

```
----+--------------+---------+---------+---------+---------+---------+--------+
SIGDO      σd11B      σd22B     σd22C     σd12B     σd12C     σd23B    σd23C
----+--------------+---------+---------+---------+---------+---------+--------+
SIGDO      0.0        0.0       0.0       0.0       0.0       0.0      0.0
----+--------------+---------+---------+---------+---------+---------+--------+


----+--------------+---------+---------+---------+---------+---------+--------+
SIGDO      σd13B      σd13C     σd33B     σd33C     σd11C
----+--------------+---------+---------+---------+---------+---------+--------+
SIGDO      0.0        0.0       0.0       0.0       0.0
----+--------------+---------+---------+---------+---------+---------+--------+
```

<u>Field</u> <u>No</u>.	<u>Field</u> <u>Name</u>	<u>Format</u>	<u>Columns</u>	<u>Description</u>

Line 1:

1	SIGDO	A5	1-5	Mnemonic name
2	σ_{d11B}	E10.3	11-20	Reference stress in region d11B
3	σ_{d22B}	E10.3	21-30	Reference stress in region d22B
4	σ_{d22C}	E10.3	31-40	Reference stress in region d22C
5	σ_{d12B}	E10.3	41-50	Reference stress in region d12B
6	σ_{d12C}	E10.3	51-60	Reference stress in region d12C
7	σ_{d23B}	E10.3	61-70	Reference stress in region d23B
8	σ_{d23C}	E10.3	71-80	Reference stress in region d23C

Line 2:

1	SIGDO	A5	1-5	Mnemonic name
2	σ_{d13B}	E10.3	11-20	Reference stress in region d13B
3	σ_{d13C}	E10.3	21-30	Reference stress in region d13C
4	σ_{d33B}	E10.3	31-40	Reference stress in region d33B
5	σ_{d33C}	E10.3	41-50	Reference stress in region d33C
6	σ_{d11C}	E10.3	51-60	Reference stress in region d11C

Remarks:

1. The reference values of the stresses are used in the stress term of the multifactor interaction relationship and are typically set to zero for convenience.

3.3.8   Interphase Data Record: DOTDO

Description: Defines reference values of interphase stress rates

Format and Example:

```
----+------------+---------+---------+---------+---------+---------+---------+
```

| DOTDO | $\dot{\sigma}_{d11B}$ | $\dot{\sigma}_{d22B}$ | $\dot{\sigma}_{d22C}$ | $\dot{\sigma}_{d12B}$ | $\dot{\sigma}_{d12C}$ | $\dot{\sigma}_{d23B}$ | $\dot{\sigma}_{d23C}$ |

```
----+------------+---------+---------+---------+---------+---------+---------+
```

| DOTDO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

```
----+------------+---------+---------+---------+---------+---------+---------+


----+------------+---------+---------+---------+---------+---------+---------+
```

| DOTDO | $\dot{\sigma}_{d13B}$ | $\dot{\sigma}_{d13C}$ | $\dot{\sigma}_{d33B}$ | $\dot{\sigma}_{d33C}$ | $\dot{\sigma}_{d11C}$ |

```
----+------------+---------+---------+---------+---------+---------+---------+
```

| DOTDO | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

```
----+------------+---------+---------+---------+---------+---------+---------+
```

Field No.	Field Name	Format	Columns	Description
Line 1:				
1	DOTDO	A5	1-5	Mnemonic name
2	$\dot{\sigma}_{d11B}$	E10.3	11-20	Reference stress rate in region d11B
3	$\dot{\sigma}_{d22B}$	E10.3	21-30	Reference stress rate in region d22B
4	$\dot{\sigma}_{d22C}$	E10.3	31-40	Reference stress rate in region d22C
5	$\dot{\sigma}_{d12B}$	E10.3	41-50	Reference stress rate in region d12B

6	$\dot{\sigma}_{d12C}$	E10.3	51-60	Reference stress rate in region d12C
7	$\dot{\sigma}_{d23B}$	E10.3	61-70	Reference stress rate in region d23B
8	$\dot{\sigma}_{d23C}$	E10.3	71-80	Reference stress rate in region d23C

Line 2:

1	DOTD0	A5	1-5	Mnemonic name
2	$\dot{\sigma}_{d13B}$	E10.3	11-20	Reference stress rate in region d13B
3	$\dot{\sigma}_{d13C}$	E10.3	21-30	Reference stress rate in region d13C
4	$\dot{\sigma}_{d33B}$	E10.3	31-40	Reference stress rate in region d33B
5	$\dot{\sigma}_{d33C}$	E10.3	41-50	Reference stress rate in region d33C
6	$\dot{\sigma}_{d11C}$	E10.3	51-60	Reference stress rate in region d11C

Remarks:

1. The reference values of the stress rates are used in the stress rate term of the multifactor interaction relationship and are typically set to zero for convenience.

3.3.9   Interphase Data Record: EXPONENTS

Description: Defines values of exponents for interphase properties in
multifactor interaction relationship

Format and Example:

```
--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS  DEX1  DEX2  DEX3  DEX4  DEX5  DEX6  DEX7  DEX8  DEX9 DEX10

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS DEX11 DEX12 DEX13 DEX14 DEX15 DEX16 DEX17 DEX18 DEX19 DEX20

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.00  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS DEX21 DEX22 DEX23 DEX24 DEX25 DEX26 DEX27 DEX28 DEX29 DEX30

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+


--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS DEX31

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+

EXPONENTS  0.50

--------+-----+-----+-----+-----+-----+-----+-----+-----+-----+----------+
```

Field No.	Field Name	Format	Columns	Description
Line 1:				
1	EXPONENTS	A9	1-9	Mnemonic name
2	DEX1	F5.2	11-15	Reserved for future use
3	DEX2	F5.2	17-21	Modulus-stress rate exponent
4	DEX3	F5.2	23-27	Modulus-stress exponent
5	DEX4	F5.2	29-33	Modulus-temperature exponent
6	DEX5	F5.2	35-39	Strength-stress rate exponent
7	DEX6	F5.2	41-45	Strength-stress exponent
8	DEX7	F5.2	47-51	Strength-temperature exponent
9	DEX8	F5.2	53-57	Poisson's ratio-stress rate exponent
10	DEX9	F5.2	59-63	Poisson's ratio-stress exponent
11	DEX10	F5.2	65-69	Poisson's ratio-temperature exponent
Line 2:				
1	EXPONENTS	A9	1-9	Mnemonic name
2	DEX11	F5.2	11-15	Reserved for future use
3	DEX12	F5.2	17-21	Reserved for future use
4	DEX13	F5.2	23-27	Reserved for future use
5	DEX14	F5.2	29-33	Heat conductivity-stress rate exponent
6	DEX15	F5.2	35-39	Heat conductivity-stress exponent
7	DEX16	F5.2	41-45	Heat conductivity-temperature exponent
8	DEX17	F5.2	47-51	CTE-stress rate exponent

9	DEX18	F5.2	53-57	CTE-stress rate exponent
10	DEX19	F5.2	59-63	CTE-temperature exponent
11	DEX20	F5.2	65-69	Reserved for future use

Line 3:

1	EXPONENTS	A9	1-9	Mnemonic name
2	DEX21	F5.2	11-15	Reserved for future use
3	DEX22	F5.2	17-21	Reserved for future use
4	DEX23	F5.2	23-27	Reserved for future use
5	DEX24	F5.2	29-33	Reserved for future use
6	DEX25	F5.2	35-39	Reserved for future use
7	DEX26	F5.2	41-45	Reserved for future use
8	DEX27	F5.2	47-51	Reserved for future use
9	DEX28	F5.2	53-57	Reserved for future use
10	DEX29	F5.2	59-63	Reserved for future use
11	DEX30	F5.2	65-69	Reserved for future use

Line 4:

1	EXPONENTS	A9	1-9	Mnemonic name
2	DEX31	F5.2	11-15	Reserved for future use

1. The various exponents listed are used in the multifactor interaction equation. For example DEX4 would be the exponent used to determine the stress effect on the matrix modulus.

$$\frac{E_{d11}}{E_{d11_o}} = \left[\frac{S_{d11} - \sigma_{d11}}{S_{d11} - \sigma_{d11_o}} \right]^{DEX3} \ldots \ldots$$

2. The values of the exponents listed above represent the default values.

3. The locations of the currently used exponents are shown below for convenient reference.

	Exponent Field Name (i.e. DEX__)		
Property	Stress Rate	Stress	Temperature
Modulus	2	3	4
Strength	5	6	7
Poisson's Ratio	8	9	10
Heat Conductivity	14	15	16
Coeff. of Thermal Exp.	17	18	19

All other locations are reserved for future use.

3.4 Sample Constituent Databank

A sample databank is provided in Figure 3.4-1 with entries for two fibers (SiC and Tungsten), two matrices (Ti-15-3 and Copper), and an interphase (a carbon coating). The databank begins with the fiber properties, followed by the matrix properties, and ends with the interphase properties.

```
----------------------------------------------------------------------

SICA   SILICON CARBIDE FIBER

FP       1 0.560E-02 0.110E+00 0.487E+04       ·

FE   0.620E+08 0.620E+08 0.300E+00 0.300E+00 0.238E+08 0.238E+08

FT   0.272E-05 0.272E-05 0.750E+00 0.750E+00 0.290E+00

FS   0.500E+06 0.650E+06 0.500E+06 0.650E+06 0.300E+06 0.300E+06

SIGFO          0.0       0.0       0.0       0.0       0.0       0.0

DOTFO          0.0       0.0       0.0       0.0       0.0       0.0

EXPONENTS  0.25  0.25  0.25  0.25  0.25  0.00  0.25  0.25  0.25  0.25

EXPONENTS  0.25  0.25  0.25  0.25  0.00  0.25  0.25  0.00  0.25  0.25

EXPONENTS  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25

EXPONENTS  0.25

TUNG   TUNGSTEN FIBER

FP       1 0.100E-01 0.683E+00 0.617E+04

FE   0.590E+08 0.590E+08 0.290E+00 0.290E+00 0.227E+08 0.227E+08

FT   0.250E-05 0.250E-05 0.828E+01 0.828E+01 0.240E-01

FS   0.390E+06 0.390E+06 0.390E+06 0.390E+06 0.236E+06 0.236E+06

SIGFO          0.0       0.0       0.0       0.0       0.0       0.0

DOTFO          0.0       0.0       0.0       0.0       0.0       0.0

EXPONENTS  0.25  0.25  0.25  0.25  0.25  0.00  0.25  0.25  0.25  0.25

EXPONENTS  0.25  0.25  0.25  0.25  0.00  0.25  0.25  0.00  0.25  0.25

EXPONENTS  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25  0.25

EXPONENTS  0.25

OVER END OF FIBER PROPERTIES

TI1S   TITANIUM MATRIX

MP   0.170E+00

ME   0.123E+08 0.320E+00 0.450E-05

MT   0.390E+00 0.120E+00

MS   0.130E+06 0.130E+06 0.780E+05 0.120E+00 0.120E+00 0.120E+00 0.120E+00

MV   0.019E+00 0.180E+04                    ·

SIGMO          0.0       0.0       0.0       0.0       0.0       0.0       0.0

SIGMO          0.0       0.0       0.0       0.0       0.0       0.0       0.0

SIGMO          0.0       0.0       0.0       0.0

DOTMO          0.0       0.0       0.0       0.0       0.0       0.0       0.0

DOTMO          0.0       0.0       0.0       0.0       0.0       0.0       0.0

DOTMO          0.0       0.0       0.0       0.0
```

Figure 3.4-1—Sample case constituent databank.

3-49

```
EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.00  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50

COPR  COPPER MATRIX

MP  0.320E+00

ME  0.177E+08 0.300E+00 0.980E-05

MT  0.193E+02 0.090E+00

MS  0.320E+05 0.320E+05 0.190E+05 0.350E+00 0.350E+00 0.350E+00 0.350E+00

MV  0.019E+00 0.198E+04

SIGMO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

SIGMO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

SIGMO        0.0      0.0      0.0      0.0

DOTMO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

DOTMO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

DOTMO        0.0      0.0      0.0      0.0

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.00  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50

OVER END OF MATRIX PROPERTIES

INTERPHASE  CARBON COATING FOR FIBERS

DP  0.172E+00 0.020E+00

DE  0.250E+07 0.220E+00 0.212E-05

DT  0.390E+00 0.120E+00

DS  0.100E+05 0.100E+05 0.100E+05 0.120E+00 0.120E+00 0.120E+00 0.120E+00

DV  0.019E+00 0.140E+04

SIGDO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

SIGDO        0.0      0.0      0.0      0.0      0.0      0.0

DOTDO        0.0      0.0      0.0      0.0      0.0      0.0      0.0

DOTDO        0.0      0.0      0.0      0.0      0.0      0.0

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.00  0.50  0.50

EXPONENTS  0.50  0.50  0.50  0.50  0.50  0.00  0.50  0.50  0.50  0.50

EXPONENTS  0.50
```

Figure 3.4-1 Concluded.

Section 4.0 Table of Contents

4.0 Postprocessing Output Files

The ten postprocessing files contain information pertaining to various behavior/response variables. As noted earlier, these files can be optionally generated at the user's convenience and essentially duplicates the same information which is reported in the primary output file, but in format from which selected output quantities can be extracted by the user and imported into graphics packages for convenient representation. The general format of each line of the postprocessing files is (5(1X,E15.6)). The first entry in each of the ten files contains the time for the current step. A description of the contents of each file is given below.

4.1 Postprocessing File 1

<u>Description</u>:   Time and temperature for each ply

<u>Format</u>:

```
---------------+---------------+---------------+---------------+---------------+
     t_i          T_ply 1         T_ply 2         .....           T_ply n
---------------+---------------+---------------+---------------+---------------+
```

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	$T_{ply\ 1}$	E15.6	18-32	Temperature of ply 1 at time t_i
3	$T_{ply\ 2}$	E15.6	34-48	Temperature of ply 2 at time t_i
$\vdots$				
n	$T_{ply\ n}$	E15.6		Temperature of ply n at time t_i

<u>Remarks</u>:

1. If there are more than four plies, the temperatures for plies five onward are continued on subsequent lines until all plies are represented.

2. The set of lines is repeated for each time step in the analysis.

4.2 Postprocessing File 2

<u>Description</u>:   Time and instantaneous fiber properties for each ply

<u>Format</u>:

t_i	27	ρ_f	E_{f11}	E_{f22}
G_{f12}	G_{f23}	ν_{f12}	ν_{f23}	C_{ff}
K_{f11}	K_{f22}	α_{f11}	α_{f22}	S_{f11T}
S_{f11C}	S_{f22T}	S_{f22C}	S_{f12}	S_{f23}
S_{f13}	ν_{f13}	G_{f13}	E_{f33}	α_{f33}
G_{f12}	G_{f23}	ν_{f13}	S_{f33T}	S_{f33C}

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	27	E15.6	18-32	Number of fiber properties
3	ρ_f	E15.6	34-48	Fiber density at time t_i
4	E_{f11}	E15.6	50-64	Fiber 11 modulus at time t_i
5	E_{f22}	E15.6	66-80	Fiber 22 modulus at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	G_{f12}	E15.6	2-16	Fiber 12 shear modulus at time t_i
2	G_{f23}	E15.6	18-32	Fiber 23 shear modulus at time t_i
3	ν_{f12}	E15.6	34-48	Fiber 12 Poisson's ratio at time t_i
4	ν_{f23}	E15.6	50-64	Fiber 23 Poisson's ratio at time t_i
5	C_{ff}	E15.6	66-80	Fiber heat capacity at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	K_{f11}	E15.6	2-16	Fiber 11 thermal conductivity at time t_i
2	K_{f22}	E15.6	18-32	Fiber 22 thermal conductivity at time t_i
3	α_{f11}	E15.6	34-48	Fiber 11 coefficient of thermal expansion at time t_i
4	α_{f22}	E15.6	50-64	Fiber 22 coefficient of thermal expansion at time t_i
5	S_{f11T}	E15.6	66-80	Fiber 11 tensile strength at

time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	S_{f11C}	E15.6	2-16	Fiber 11 compressive strength at time t_i
2	S_{f22T}	E15.6	18-32	Fiber 22 tensile strength at time t_i
3	S_{f22C}	E15.6	34-48	Fiber 22 compressive strength at time t_i
4	S_{f12}	E15.6	50-64	Fiber 12 shear strength at time t_i
5	S_{f23}	E15.6	66-80	Fiber 23 shear strength at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	S_{f13}	E15.6	2-16	Fiber 13 shear strength at time t_i
2	ν_{f13}	E15.6	18-32	Fiber 13 Poisson's ratio at time t_i
3	G_{f13}	E15.6	34-48	Fiber 13 shear modulus at time t_i
4	E_{f33}	E15.6	50-64	Fiber 33 modulus at time t_i
5	α_{f33}	E15.6	66-80	Fiber 33 coefficient of thermal expansion at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	G_{f12}	E15.6	2-16	Fiber 12 shear modulus at time t_i
2	G_{f23}	E15.6	18-32	Fiber 23 shear modulus at time t_i
3	ν_{f13}	E15.6	34-48	Fiber 13 Poisson's ratio at time t_i
4	S_{f33T}	E15.6	50-64	Fiber 33 tensile strength at time

5   S_{f33C} E15.6   66-80   Fiber 33 compressive strength at time t_i

Remarks:

1.   The set of six lines is repeated for each time step in the analysis.

4.3 Postprocessing File 3

<u>Description</u>:   Time and instantaneous matrix properties for each ply

<u>Format</u>:

t_i	59	ρ_m	E_{m11}	E_{m22A}
E_{m22B}	E_{m22C}	E_{m22}	G_{m12A}	G_{m12B}
G_{m12C}	G_{m12}	G_{m23A}	G_{m23B}	G_{m23C}
G_{m23}	ν_{m12}	ν_{m23}	C_{fm}	K_{m11}
K_{m22}	α_{m11}	α_{m22A}	α_{m22B}	α_{m22C}
α_{m22}	S_{m11T}	S_{m11C}	S_{m22T}	S_{m22C}
S_{m12}	S_{m23}	S_{m13}	G_{m13A}	G_{m13B}

G_{m13C}	G_{m13}	ν_{m13}	ν_{m12A}	ν_{m12B}
ν_{m12C}	ν_{m23A}	ν_{m23B}	ν_{m23C}	ν_{m13A}
ν_{m13B}	ν_{m13C}	E_{m33A}	E_{m33B}	E_{m33C}
E_{m33}	α_{m33A}	α_{m33B}	α_{m33C}	α_{m33}
E_{m11A}	E_{m11B}	E_{m11C}	S_{m33T}	S_{m33C}

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	59	E15.6	18-32	Number of matrix properties
3	ρ_m	E15.6	34-48	Matrix density at time t_i
4	E_{m11}	E15.6	50-64	Matrix 11 modulus at time t_i
5	E_{m22A}	E15.6	66-80	Matrix 22A modulus at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	E_{m22B}	E15.6	2-16	Matrix 22B modulus at time t_i
2	E_{m22C}	E15.6	18-32	Matrix 22C modulus at time t_i
3	E_{m22}	E15.6	34-48	Matrix 22 modulus at time t_i
4	G_{m12A}	E15.6	50-64	Matrix 12A shear modulus at time t_i
5	G_{m12B}	E15.6	66-80	Matrix 12B shear modulus at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	G_{m12C}	E15.6	2-16	Matrix 12C shear modulus at time t_i
2	G_{m12}	E15.6	18-32	Matrix 12 shear modulus at time t_i
3	G_{m23A}	E15.6	34-48	Matrix 23A shear modulus at time t_i
4	G_{m23B}	E15.6	50-64	Matrix 23B shear modulus at time t_i
5	G_{m23C}	E15.6	66-80	Matrix 23C shear modulus at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	G_{m23}	E15.6	2-16	Matrix 23 shear modulus at time t_i
2	ν_{m12}	E15.6	18-32	Matrix 12 Poisson's ratio at time t_i
3	ν_{m23}	E15.6	34-48	Matrix 23 Poisson's ratio at time t_i
4	C_{fm}	E15.6	50-64	Matrix heat capacity at time t_i
5	K_{m11}	E15.6	66-80	Matrix 11 thermal conductivity at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	K_{m22}	E15.6	2-16	Matrix 22 thermal conductivity at time t_i
2	α_{m11}	E15.6	18-32	Matrix 11 coefficient of thermal expansion at time t_i
3	α_{m22A}	E15.6	34-48	Matrix 22A coefficient of thermal expansion at time t_i
4	α_{m22B}	E15.6	50-64	Matrix 22B coefficient of thermal expansion at time t_i
5	α_{m22C}	E15.6	66-80	Matrix 22C coefficient of thermal expansion at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	α_{m22}	E15.6	2-16	Matrix 22 coefficient of thermal expansion at time t_i
2	S_{m11T}	E15.6	18-32	Matrix 11 tensile strength at time t_i
3	S_{m11C}	E15.6	34-48	Matrix 11 compressive strength at time t_i
4	S_{m22T}	E15.6	50-64	Matrix 22 tensile strength at time t_i
5	S_{m22C}	E15.6	66-80	Matrix 22 compressive strength at time t_i

Line 7:

Field No.	Field Name	Format	Columns	Description
1	S_{m12}	E15.6	2-16	Matrix 12 shear strength at time t_i
2	S_{m23}	E15.6	18-32	Matrix 23 shear strength at time t_i
3	S_{m13}	E15.6	34-48	Matrix 13 shear strength at time t_i
4	G_{m13A}	E15.6	50-64	Matrix 13A shear modulus at time t_i
5	G_{m13B}	E15.6	66-80	Matrix 13B shear modulus at time t_i

Line 8:

Field No.	Field Name	Format	Columns	Description
1	G_{m13C}	E15.6	2-16	Matrix 13C shear modulus at time t_i
2	G_{m13}	E15.6	18-32	Matrix 13 shear modulus at time t_i
3	ν_{m13}	E15.6	34-48	Matrix 13 Poisson's ratio at time t_i
4	ν_{m12A}	E15.6	50-64	Matrix 12A Poisson's ratio at time t_i
5	ν_{m12B}	E15.6	66-80	Matrix 12B Poisson's ratio at time t_i

Line 9:

Field No.	Field Name	Format	Columns	Description
1	ν_{m12C}	E15.6	2-16	Matrix 12C Poisson's ratio at time t_i
2	ν_{m23A}	E15.6	18-32	Matrix 23A Poisson's ratio at time t_i
3	ν_{m23B}	E15.6	34-48	Matrix 23B Poisson's ratio at time t_i
4	ν_{m23C}	E15.6	50-64	Matrix 23C Poisson's ratio at time t_i
5	ν_{m13A}	E15.6	66-80	Matrix 13A Poisson's ratio at time t_i

Line 10:

Field No.	Field Name	Format	Columns	Description
1	ν_{m13B}	E15.6	2-16	Matrix 13B Poisson's ratio at time t_i
2	ν_{m13C}	E15.6	18-32	Matrix 13C Poisson's ratio at time t_i
3	E_{m33A}	E15.6	34-48	Matrix 33A modulus at time t_i
4	E_{m33B}	E15.6	50-64	Matrix 33B modulus at time t_i
5	E_{m33C}	E15.6	66-80	Matrix 33C modulus at time t_i

Line 11:

Field No.	Field Name	Format	Columns	Description
1	E_{m33}	E15.6	2-16	Matrix 33 modulus at time t_i
2	α_{m33A}	E15.6	18-32	Matrix 33A coefficient of thermal expansion at time t_i
3	α_{m33B}	E15.6	34-48	Matrix 33B coefficient of thermal expansion at time t_i
4	α_{m33C}	E15.6	50-64	Matrix 33C coefficient of thermal expansion at time t_i
5	α_{m33}	E15.6	66-80	Matrix 33 coefficient of thermal expansion at time t_i

Line 12:

Field No.	Field Name	Format	Columns	Description
1	E_{m11A}	E15.6	2-16	Matrix 11A modulus at time t_i
2	E_{m11B}	E15.6	18-32	Matrix 11B modulus at time t_i
3	E_{m11C}	E15.6	34-48	Matrix 11C modulus at time t_i
4	S_{m33T}	E15.6	50-64	Matrix 33 tensile strength at time t_i
5	S_{m33C}	E15.6	66-80	Matrix 33 compressive strength at time t_i

Remarks:

1. The set of twelve lines is repeated for each time step in the analysis.

4.4 Postprocessing File 4

Description: Time and instantaneous interphase properties for each ply

Format:

t_i	48	ρ_d	E_{d11}	E_{d22B}
E_{d22C}	E_{d22}	G_{d12B}	G_{d12C}	G_{d12}
G_{d23B}	G_{d23C}	G_{d23}	ν_{d12}	ν_{d23}
C_{fd}	K_{d11}	K_{d22}	α_{d11}	α_{d22B}
α_{d22C}	α_{d22}	S_{d11T}	S_{d11C}	S_{d22T}
S_{d22C}	S_{d12}	S_{d23}	S_{d13}	G_{d13B}

G_{d13C}	G_{d13}	ν_{d13}	ν_{d12B}	ν_{d12C}
ν_{d23B}	ν_{d23C}	ν_{d13B}	ν_{d13C}	E_{d33B}
E_{d33C}	E_{d33}	α_{d33B}	α_{d33C}	α_{d33}
E_{d11B}	E_{d11C}	S_{d33T}	S_{d33C}	

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	48	E15.6	18-32	Number of interphase properties
3	ρ_d	E15.6	34-48	Interphase density at time t_i
4	E_{d11}	E15.6	50-64	Interphase 11 modulus at time t_i
5	E_{d22B}	E15.6	66-80	Interphase 22B modulus at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	E_{d22C}	E15.6	2-16	Interphase 22C modulus at time t_i
2	E_{d22}	E15.6	18-32	Interphase 22 modulus at time t_i
3	G_{d12B}	E15.6	34-48	Interphase 12B shear modulus at time t_i
4	G_{d12C}	E15.6	50-64	Interphase 12C shear modulus at time t_i
5	G_{d12}	E15.6	66-80	Interphase 12 shear modulus at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	G_{d23B}	E15.6	2-16	Interphase 23B shear modulus at time t_i
2	G_{d23C}	E15.6	18-32	Interphase 23C shear modulus at time t_i
3	G_{d23}	E15.6	34-48	Interphase 23 shear modulus at time t_i
4	ν_{d12}	E15.6	50-64	Interphase 12 Poisson's ratio at time t_i
5	ν_{d23}	E15.6	66-80	Interphase 23 Poisson's ratio at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	C_{fd}	E15.6	2-16	Interphase heat capacity at time t_i
2	K_{d11}	E15.6	18-32	Interphase 11 thermal conductivity at time t_i
3	K_{d22}	E15.6	34-48	Interphase 22 thermal conductivity at time t_i
4	α_{d11}	E15.6	50-64	Interphase 11 coefficient of thermal expansion at time t_i
5	α_{d22B}	E15.6	66-80	Interphase 22B coefficient of thermal expansion at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	α_{d22C}	E15.6	2-16	Interphase 22C coefficient of thermal expansion at time t_i
2	α_{d22}	E15.6	18-32	Interphase 22 coefficient of thermal expansion at time t_i
3	S_{d11T}	E15.6	34-48	Interphase 11 tensile strength at time t_i
4	S_{d11C}	E15.6	50-64	Interphase 11 compressive strength at time t_i
5	S_{d22T}	E15.6	66-80	Interphase 22 tensile strength at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	S_{d22C}	E15.6	2-16	Interphase 22 compressive strength at time t_i
2	S_{d12}	E15.6	18-32	Interphase 12 shear strength at time t_i
3	S_{d23}	E15.6	34-48	Interphase 23 shear strength at time t_i
4	S_{d13}	E15.6	50-64	Interphase 13 shear strength at time t_i
5	G_{d13B}	E15.6	66-80	Interphase 13B shear modulus at time t_i

Line 7:

Field No.	Field Name	Format	Columns	Description
1	G_{d13C}	E15.6	2-16	Interphase 13C shear modulus at time t_i
2	G_{d13}	E15.6	18-32	Interphase 13 shear modulus at time t_i
3	ν_{d13}	E15.6	34-48	Interphase 13 Poisson's ratio at time t_i
4	ν_{d12B}	E15.6	50-64	Interphase 12B Poisson's ratio at time t_i
5	ν_{d12C}	E15.6	66-80	Interphase 12C Poisson's ratio at time t_i

Line 8:

Field No.	Field Name	Format	Columns	Description
1	ν_{d23B}	E15.6	2-16	Interphase 23B Poisson's ratio at time t_i
2	ν_{d23C}	E15.6	18-32	Interphase 23C Poisson's ratio at time t_i
3	ν_{d13B}	E15.6	34-48	Interphase 13B Poisson's ratio at time t_i
4	ν_{d13C}	E15.6	50-64	Interphase 13C Poisson's ratio at time t_i
5	E_{d33B}	E15.6	66-80	Interphase 33B modulus at time t_i

Line 9:

Field No.	Field Name	Format	Columns	Description
1	E_{d33C}	E15.6	2-16	Interphase 33C modulus at time t_i
2	E_{d33}	E15.6	18-32	Interphase 33 modulus at time t_i
3	α_{d33B}	E15.6	34-48	Interphase 33B coefficient of thermal expansion at time t_i
4	α_{d33C}	E15.6	50-64	Interphase 33C coefficient of thermal expansion at time t_i
5	α_{d33}	E15.6	66-80	Interphase 33 coefficient of thermal expansion at time t_i

Line 10:

Field No.	Field Name	Format	Columns	Description
1	E_{d11B}	E15.6	2-16	Interphase 11B modulus at time t_i
2	E_{d11C}	E15.6	18-32	Interphase 11C modulus at time t_i
3	S_{d33T}	E15.6	34-48	Interphase 33 tensile strength at time t_i
4	S_{d33C}	E15.6	50-64	Interphase 33 compressive strength at time t_i

Remarks:

1. The set of ten lines is repeated for each time step in the analysis.

4.5 Postprocessing File 5

<u>Description</u>:　Time and instantaneous ply properties for each ply

<u>Format</u>:

t_i	27	ρ_1	E_{111}	E_{122}
E_{133}	G_{112}	G_{123}	G_{113}	ν_{112}
ν_{123}	ν_{113}	C_{f1}	K_{111}	K_{122}
K_{133}	α_{111}	α_{122}	α_{133}	S_{111T}
S_{111C}	S_{122T}	S_{122C}	S_{133T}	S_{133C}
S_{112}	S_{123}	S_{113}		

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	27	E15.6	18-32	Number of ply properties
3	ρ_1	E15.6	34-48	Ply density at time t_i
4	E_{111}	E15.6	50-64	Ply 11 modulus at time t_i
5	E_{122}	E15.6	66-80	Ply 22 modulus at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	E_{133}	E15.6	2-16	Ply 33 modulus at time t_i
2	G_{112}	E15.6	18-32	Ply 12 shear modulus at time t_i
3	G_{123}	E15.6	34-48	Ply 23 shear modulus at time t_i
4	G_{113}	E15.6	50-64	Ply 13 shear modulus at time t_i
5	ν_{112}	E15.6	66-80	Ply 12 Poisson's ratio at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	ν_{123}	E15.6	2-16	Ply 23 Poisson's ratio at time t_i
2	ν_{113}	E15.6	18-32	Ply 13 Poisson's ratio at time t_i
3	C_{f1}	E15.6	34-48	Ply heat capacity at time t_i
4	K_{111}	E15.6	50-64	Ply 11 thermal conductivity at time t_i
5	K_{122}	E15.6	66-80	Ply 22 thermal conductivity at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	K_{133}	E15.6	2-16	Ply 33 thermal conductivity at time t_i
2	α_{111}	E15.6	18-32	Ply 11 coefficient of thermal expansion at time t_i
3	α_{122}	E15.6	34-48	Ply 22 coefficient of thermal expansion at time t_i
4	α_{133}	E15.6	50-64	Ply 33 coefficient of thermal expansion at time t_i
5	S_{111T}	E15.6	66-80	Ply 11 tensile strength at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	S_{111C}	E15.6	2-16	Ply 11 compressive strength at time t_i
2	S_{122T}	E15.6	18-32	Ply 22 tensile strength at time t_i
3	S_{122C}	E15.6	34-48	Ply 22 compressive strength at time t_i
4	S_{133T}	E15.6	50-64	Ply 33 tensile strength at time t_i
5	S_{133C}	E15.6	66-80	Ply 33 compressive strength at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	S_{112}	E15.6	2-16	Ply 12 shear strength at time t_i
2	S_{123}	E15.6	18-32	Ply 23 shear strength at time t_i
3	S_{113}	E15.6	34-48	Ply 13 shear strength at time t_i

Remarks:

1. The set of six lines is repeated for each time step in the analysis.

4.6 Postprocessing File 6

Description: Time and instantaneous fiber stresses and strains for each ply

Format:

```
---------------+---------------+---------------+---------------+---------------+

    t_i              7            σ_f11          σ_f22          σ_f12

---------------+---------------+---------------+---------------+---------------+

---------------+---------------+---------------+---------------+---------------+

   σ_f23          σ_f13          σ_f33             7            ε_f11

---------------+---------------+---------------+---------------+---------------+

---------------+---------------+---------------+---------------+---------------+

   ε_f22          ε_f12          ε_f23          ε_f13          ε_f33

---------------+---------------+---------------+---------------+---------------+
```

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	7	E15.6	18-32	Number of fiber stresses
3	σ_{f11}	E15.6	34-48	Fiber 11 stress at time t_i
4	σ_{f22}	E15.6	50-64	Fiber 22 stress at time t_i
5	σ_{f12}	E15.6	66-80	Fiber 12 shear stress at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	σ_{f23}	E15.6	2-16	Fiber 23 shear stress at time t_i
2	σ_{f13}	E15.6	18-32	Fiber 13 shear stress at time t_i
3	σ_{f33}	E15.6	34-48	Fiber 33 stress at time t_i
4	7	E15.6	50-64	Number of fiber strains
5	ε_{f11}	E15.6	66-80	Fiber 11 strain at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	ε_{f22}	E15.6	2-16	Fiber 22 strain at time t_i
2	ε_{f12}	E15.6	18-32	Fiber 12 shear strain at time t_i
3	ε_{f23}	E15.6	34-48	Fiber 23 shear strain at time t_i
4	ε_{f13}	E15.6	50-64	Fiber 13 shear strain at time t_i
5	ε_{f33}	E15.6	66-80	Fiber 23 strain at time t_i

Remarks:

1. The set of three lines is repeated for each time step in the analysis.

4.7 Postprocessing File 7

<u>Description</u>:   Time and instantaneous matrix stresses and strains for each ply

<u>Format</u>:

t_i	19	σ_{m11A}	σ_{m22A}	σ_{m22B}
σ_{m22C}	σ_{m12A}	σ_{m12B}	σ_{m12C}	σ_{m23A}
σ_{m23B}	σ_{m23C}	σ_{m13A}	σ_{m13B}	σ_{m13C}
σ_{m33A}	σ_{m33B}	σ_{m33C}	σ_{m11B}	σ_{m11C}
19	ε_{m11A}	ε_{m22A}	ε_{m22B}	ε_{m22C}
ε_{m12A}	ε_{m12B}	ε_{m12C}	ε_{m23A}	ε_{m23B}
ε_{m23C}	ε_{m13A}	ε_{m13B}	ε_{m13C}	ε_{m33A}

```
--------------+---------------+-------------+---------------+---------------+
    ε_m33B          ε_m33C          ε_m11B          ε_m11C
--------------+---------------+-------------+---------------+---------------+
```

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	19	E15.6	18-32	Number of matrix stresses
3	σ_{m11A}	E15.6	34-48	Matrix 11A stress at time t_i
4	σ_{m22A}	E15.6	50-64	Matrix 22A stress at time t_i
5	σ_{m22B}	E15.6	66-80	Matrix 12B stress at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	σ_{m22C}	E15.6	2-16	Matrix 22B stress at time t_i
2	σ_{m12A}	E15.6	18-32	Matrix 12A shear stress at time t_i
3	σ_{m12B}	E15.6	34-48	Matrix 12B shear stress at time t_i
4	σ_{m12C}	E15.6	50-64	Matrix 12C shear stress at time t_i
5	σ_{m23A}	E15.6	66-80	Matrix 23A shear stress at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	σ_{m23B}	E15.6	2-16	Matrix 23B stress at time t_i
2	σ_{m23C}	E15.6	18-32	Matrix 23C shear stress at time t_i
3	σ_{m13A}	E15.6	34-48	Matrix 13A shear stress at time t_i
4	σ_{m13B}	E15.6	50-64	Matrix 13B shear stress at time t_i
5	σ_{m13C}	E15.6	66-80	Matrix 13C shear stress at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	σ_{m33A}	E15.6	2-16	Matrix 33A stress at time t_i
2	σ_{m33B}	E15.6	18-32	Matrix 33B stress at time t_i
3	σ_{m33C}	E15.6	34-48	Matrix 33C stress at time t_i
4	σ_{m11B}	E15.6	50-64	Matrix 11B stress at time t_i
5	σ_{m11C}	E15.6	66-80	Matrix 11C stress at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	19	E15.6	2-16	Number of matrix strains
2	ε_{m11A}	E15.6	18-32	Matrix 11A strain at time t_i
3	ε_{m22A}	E15.6	34-48	Matrix 22A strain at time t_i
4	ε_{m22B}	E15.6	50-64	Matrix 22B strain at time t_i
5	ε_{m22C}	E15.6	66-80	Matrix 22C strain at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	ε_{m12A}	E15.6	2-16	Matrix 12A shear strain at time t_i
2	ε_{m12B}	E15.6	18-32	Matrix 12B shear strain at time t_i
3	ε_{m12C}	E15.6	34-48	Matrix 12C shear strain at time t_i
4	ε_{m23A}	E15.6	50-64	Matrix 23A shear strain at time t_i
5	ε_{m23B}	E15.6	66-80	Matrix 23B shear strain at time t_i

Line 7:

Field No.	Field Name	Format	Columns	Description
1	ε_{m23C}	E15.6	2-16	Matrix 23C shear strain at time t_i
2	ε_{m13A}	E15.6	18-32	Matrix 13A shear strain at time t_i
3	ε_{m13B}	E15.6	34-48	Matrix 13B shear strain at time t_i
4	ε_{m13C}	E15.6	50-64	Matrix 13C shear strain at time t_i
5	ε_{m33A}	E15.6	66-80	Matrix 33A strain at time t_i

Line 8:

Field No.	Field Name	Format	Columns	Description
1	ε_{m33B}	E15.6	2-16	Matrix 33B strain at time t_i
2	ε_{m33C}	E15.6	18-32	Matrix 33C strain at time t_i
3	ε_{m11B}	E15.6	34-48	Matrix 11B strain at time t_i
4	ε_{m11C}	E15.6	50-64	Matrix 11C strain at time t_i

Remarks:

1. The set of eight lines is repeated for each time step in the analysis.

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4.8 Postprocessing File 8

<u>Description</u>: Time and instantaneous interphase stresses and strains for each ply

<u>Format</u>:

t_i	13	σ_{d11B}	σ_{d22B}	σ_{d22C}

σ_{d12B}	σ_{d12C}	σ_{d23B}	σ_{d23C}	σ_{d13B}

σ_{d13C}	σ_{d33B}	σ_{d33C}	σ_{d11C}	13

ε_{d11B}	ε_{d22B}	ε_{d22C}	ε_{d12B}	ε_{d12C}

ε_{d23B}	ε_{d23C}	ε_{d13B}	ε_{d13C}	ε_{d33B}

ε_{d33C}	ε_{d11C}			

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	13	E15.6	18-32	Number of interphase stresses
3	σ_{d11B}	E15.6	34-48	Interphase 11B stress at time t_i
4	σ_{d22B}	E15.6	50-64	Interphase 22B stress at time t_i
5	σ_{d22C}	E15.6	66-80	Interphase 22C stress at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	σ_{d12B}	E15.6	2-16	Interphase 12B shear stress at time t_i
2	σ_{d12C}	E15.6	18-32	Interphase 12C shear stress at time t_i
3	σ_{d23B}	E15.6	34-48	Interphase 23B shear stress at time t_i
4	σ_{d23C}	E15.6	50-64	Interphase 23C shear stress at time t_i
5	σ_{d13B}	E15.6	66-80	Interphase 13B shear stress at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	σ_{d13C}	E15.6	2-16	Interphase 13C shear stress at time t_i
2	σ_{d33B}	E15.6	18-32	Interphase 33B stress at time t_i
3	σ_{d33C}	E15.6	34-48	Interphase 33C stress at time t_i
4	σ_{d11C}	E15.6	50-64	Interphase 11C stress at time t_i
5	13	E15.6	66-80	Number of interphase strains

Line 4:

Field No.	Field Name	Format	Columns	Description
1	ε_{d11B}	E15.6	2-16	Interphase 11B strain at time t_i
2	ε_{d22B}	E15.6	18-32	Interphase 22B strain at time t_i
3	ε_{d22C}	E15.6	34-48	Interphase 22C strain at time t_i
4	ε_{d12B}	E15.6	50-64	Interphase 12B shear strain at time t_i
5	ε_{d12C}	E15.6	66-80	Interphase 12C shear strain at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	ε_{d23B}	E15.6	2-16	Interphase 23B shear strain at time t_i
2	ε_{d23C}	E15.6	18-32	Interphase 23C shear strain at time t_i
3	ε_{d13B}	E15.6	34-48	Interphase 13B shear strain at time t_i
4	ε_{d13C}	E15.6	50-64	Interphase 13C shear strain at time t_i
5	ε_{d33B}	E15.6	66-80	Interphase 33B strain at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	ε_{d33C}	E15.6	2-16	Interphase 33C strain at time t_i
2	ε_{d11C}	E15.6	18-32	Interphase 13C strain at time t_i

Remarks:

1. The set of six lines is repeated for each time step in the analysis.

4.9 Postprocessing File 9

Description: Time, incremental composite strains, incremental ply stresses, incremental ply strains, and incremental composite stresses

Format:

t_i	ε_{cxx}	ε_{cyy}	ε_{cxy}	σ_{111}

σ_{122}	σ_{112}	σ_{113}	σ_{123}	ε_{111}

ε_{122}	ε_{112}	ε_{113}	ε_{123}	σ_{cxx}

σ_{cyy}	σ_{cxy}	σ_{cxz}	σ_{cyz}	σ_{czz}

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	ε_{cxx}	E15.6	18-32	Composite xx strain at time t_i
3	ε_{cyy}	E15.6	34-48	Composite yy strain at time t_i
4	ε_{cxy}	E15.6	50-64	Composite xy shear strain at time t_i
5	σ_{111}	E15.6	66-80	Ply 11 stress at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	σ_{122}	E15.6	2-16	Ply 22 stress at time t_i
2	σ_{112}	E15.6	18-32	Ply 12 shear stress at time t_i
3	σ_{113}	E15.6	34-48	Ply 13 shear stress at time t_i
4	σ_{123}	E15.6	50-64	Ply 23 shear stress at time t_i
5	ε_{111}	E15.6	66-80	Ply 11 strain at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	ε_{122}	E15.6	2-16	Ply 22 strain at time t_i
2	ε_{112}	E15.6	18-32	Ply 12 shear strain at time t_i
3	ε_{113}	E15.6	34-48	Ply 13 shear strain at time t_i
4	ε_{123}	E15.6	50-64	Ply 23 shear strain at time t_i
5	σ_{cxx}	E15.6	66-80	Composite xx stress at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	σ_{cyy}	E15.6	2-16	Composite yy stress at time t_i
2	σ_{cxy}	E15.6	18-32	Composite xy shear stress at time t_i
3	σ_{cxz}	E15.6	34-48	Composite xz shear strain at time t_i
4	σ_{cyz}	E15.6	50-64	Composite yz shear strain at time t_i
5	σ_{czz}	E15.6	66-80	Composite zz stress at time t_i

Remarks:

1. The set of four lines is repeated for each time step in the analysis.

4.10 Postprocessing File 10

<u>Description</u>:   Time and instantaneous composite properties

<u>Format</u>:

t_i	ρ_c	T_c	C_{c11}	C_{c12}
C_{c13}	C_{c22}	C_{c23}	C_{c33}	C_{c44}
C_{c55}	C_{c66}	α_{c11}	α_{c22}	α_{c33}
K_{c11}	K_{c22}	K_{c33}	C_{fc}	E_{c11}
E_{c22}	E_{c33}	G_{c23}	G_{c31}	G_{c12}
ν_{c12}	ν_{c21}	ν_{c13}	ν_{c31}	ν_{c23}
ν_{c32}	z_c	ψ_{cMDE}	C_{c11}	C_{c12}

C_{c13}	C_{c22}	C_{c23}	C_{c33}	E_{c11}
E_{c22}	G_{c12}	ν_{c12}	ν_{c21}	ν_{c13}
ν_{c31}	ν_{c23}	ν_{c32}	α_{c11}	α_{c22}
α_{c12}	K_{c11}	K_{c22}	K_{c12}	C_{fc}
vacant	vacant	vacant	vacant	vacant
vacant	vacant	vacant		

Line 1:

Field No.	Field Name	Format	Columns	Description
1	t_i	E15.6	2-16	Time at each load/time step
2	ρ_c	E15.6	18-32	Composite density at time t_i
3	T_c	E15.6	34-48	Composite temperature at time t_i
4	C_{c11}	E15.6	50-64	3-D composite 11 component of stiffness matrix at time t_i
5	C_{c12}	E15.6	66-80	3-D composite 12 component of stiffness matrix at time t_i

Line 2:

Field No.	Field Name	Format	Columns	Description
1	C_{c13}	E15.6	2-16	3-D composite 13 component of stiffness matrix at time t_i
2	C_{c22}	E15.6	18-32	3-D composite 22 component of stiffness matrix at time t_i
3	C_{c23}	E15.6	34-48	3-D composite 23 component of stiffness matrix at time t_i
4	C_{c33}	E15.6	50-64	3-D composite 33 component of stiffness matrix at time t_i
5	C_{c44}	E15.6	66-80	3-D composite 44 component of stiffness matrix at time t_i

Line 3:

Field No.	Field Name	Format	Columns	Description
1	C_{c55}	E15.6	2-16	3-D composite 55 component of stiffness matrix at time t_i
2	C_{c66}	E15.6	18-32	3-D composite 66 component of stiffness matrix at time t_i
3	α_{c11}	E15.6	34-48	3-D composite 11 coefficient of thermal expansion at time t_i
4	α_{c22}	E15.6	50-64	3-D composite 22 coefficient of thermal expansion at time t_i
5	α_{c33}	E15.6	66-80	3-D composite 33 coefficient of thermal expansion at time t_i

Line 4:

Field No.	Field Name	Format	Columns	Description
1	K_{c11}	E15.6	2-16	3-D composite 11 thermal conductivity at time t_i
2	K_{c22}	E15.6	18-32	3-D composite 22 thermal conductivity at time t_i
3	K_{c33}	E15.6	34-48	3-D composite 33 thermal conductivity at time t_i
4	C_{fc}	E15.6	50-64	3-D composite heat capacity at time t_i
5	E_{c11}	E15.6	66-80	3-D composite 11 modulus at time t_i

Line 5:

Field No.	Field Name	Format	Columns	Description
1	E_{c22}	E15.6	2-16	3-D composite 22 modulus at time t_i
2	E_{c33}	E15.6	18-32	3-D composite 33 modulus at time t_i
3	G_{c23}	E15.6	34-48	3-D composite 23 shear modulus at time t_i
4	G_{c31}	E15.6	50-64	3-D composite 31 shear modulus at time t_i
5	G_{c12}	E15.6	66-80	3-D composite 12 shear modulus at time t_i

Line 6:

Field No.	Field Name	Format	Columns	Description
1	ν_{c12}	E15.6	2-16	3-D composite 12 Poisson's ratio at time t_i
2	ν_{c21}	E15.6	18-32	3-D composite 21 Poisson's ratio at time t_i
3	ν_{c13}	E15.6	34-48	3-D composite 13 Poisson's ratio at time t_i
4	ν_{c31}	E15.6	50-64	3-D composite 31 Poisson's ratio at time t_i
5	ν_{c23}	E15.6	66-80	3-D composite 23 Poisson's ratio at time t_i

Line 7:

Field No.	Field Name	Format	Columns	Description
1	ν_{c32}	E15.6	2-16	3-D composite 32 Poisson's ratio at time t_i
2	z_c	E15.6	18-32	Composite thickness
3	ψ_{cMDE}	E15.6	34-48	Composite modified distortion energy
4	C_{c11}	E15.6	50-64	2-D composite 11 component of stiffness matrix at time t_i
5	C_{c12}	E15.6	66-80	2-D composite 12 component of stiffness matrix at time t_i

Line 8:

Field No.	Field Name	Format	Columns	Description
1	C_{c13}	E15.6	2-16	2-D composite 13 component of stiffness matrix at time t_i
2	C_{c22}	E15.6	18-32	2-D composite 22 component of stiffness matrix at time t_i
3	C_{c23}	E15.6	34-48	2-D composite 23 component of stiffness matrix at time t_i
4	C_{c33}	E15.6	50-64	2-D composite 33 component of stiffness matrix at time t_i
5	E_{c11}	E15.6	66-80	2-D composite 11 modulus at time t_i

Line 9:

Field No.	Field Name	Format	Columns	Description
1	E_{c22}	E15.6	2-16	2-D composite 22 modulus at time t_i
2	G_{c12}	E15.6	18-32	2-D composite 12 shear modulus at time t_i
3	ν_{c12}	E15.6	34-48	2-D composite 12 Poisson's ratio at time t_i
4	ν_{c21}	E15.6	50-64	2-D composite 21 Poisson's ratio at time t_i
5	ν_{c13}	E15.6	66-80	2-D composite 13 Poisson's ratio at time t_i

Line 10:

Field No.	Field Name	Format	Columns	Description
1	ν_{c31}	E15.6	2-16	2-D composite 31 Poisson's ratio at time t_i
2	ν_{c23}	E15.6	18-32	2-D composite 23 Poisson's ratio at time t_i
3	ν_{c32}	E15.6	34-48	2-D composite 32 Poisson's ratio at time t_i
4	α_{c11}	E15.6	50-64	2-D composite 11 coefficient of thermal expansion at time t_i
5	α_{c22}	E15.6	66-80	2-D composite 22 coefficient of thermal expansion at time t_i

Line 11:

Field No.	Field Name	Format	Columns	Description
1	α_{c12}	E15.6	2-16	2-D composite 12 coefficient of thermal expansion at time t_i
2	K_{c11}	E15.6	18-32	2-D composite 11 thermal conductivity at time t_i
3	K_{c22}	E15.6	34-48	2-D composite 22 thermal conductivity at time t_i
4	K_{c12}	E15.6	50-64	2-D composite 12 thermal conductivity at time t_i
5	C_{fc}	E15.6	66-80	2-D composite heat capacity

Line 12:

Field No.	Field Name	Format	Columns	Description
1	vacant	E15.6	2-16	reserved for future use
2	vacant	E15.6	18-32	reserved for future use
3	vacant	E15.6	34-48	reserved for future use
4	vacant	E15.6	50-64	reserved for future use
5	vacant	E15.6	66-80	reserved for future use

Line 13:

Field No.	Field Name	Format	Columns	Description
1	vacant	E15.6	2-16	reserved for future use
2	vacant	E15.6	18-32	reserved for future use
3	vacant	E15.6	34-48	reserved for future use

Remarks:

1. The set of thirteen lines is repeated for each time step in the analysis.

5.0 References

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H.-J. Lee, P.K. Gotsis, P.L.N. Murthy, and D.A. Hopkins

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Lewis Research Center
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13. ABSTRACT (Maximum 200 words)

METCAN (Metal Matrix Composite Analyzer) is a computer code developed at NASA Lewis Research Center to simulate the high temperature nonlinear behavior of metal matrix composites. An updated version of the METCAN User's Manual is presented. The manual provides the user a step by step outline of the procedure necessary to run METCAN. The preparation of the input files is demonstrated, the output files explained, and the sample problems presented to highlight various features of METCAN. An overview of the geometric conventions, micromechanical unit cell, and the nonlinear constitutive relationship is also provided.

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